

Attachment C
DETAILS ON THE STATISTICAL TESTS

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We begin our discussion of the regression based tests by describing the inherent assumptions of the regression models used, both for the linear regression model used in the EPA tests and for better-fitting quadratic regression models. Although we show that the quadratic regression model fits statistically significantly better, we nevertheless performed the linear regression tests on the 50,000 mile data, both to repeat the EPA procedures from the 1978 waiver application and because the linear fits are used as input to MOBILE4. The linear and quadratic regression tests are here described in detail: slopes and quadratic coefficient tests, deterioration factors tests, violation mileage tests, and the maximum percentage of vehicles failing standard test. Finally, we discuss the cause-or-contribute test, which has two versions depending upon whether a linear or quadratic regression model is used.

Note that in this description we frequently imply that three vehicles were tested for each fuel for each of the eight model groups. We note that for model group D one of the clear-fuel vehicle was omitted from the data set for analysis because of modifications in the emission control system; the statistical tests were appropriately modified for this special case.

NONREGRESSION TESTS

Assumptions

Assumptions of Constant Test-to-Test Variances Across Mileages

A crucial assumption in the nonregression analyses is the assumption that the variance of each emission test observation does not depend on mileage, although it will usually depend on vehicular model, fuel, and pollutant. Effectively, we do not assume that the variability increases with emissions, since emissions generally increase with mileage. In this section we discuss the plausibility of this assumption.

An examination of the data plots (Attachment B) shows that there is no apparent pattern in variability as mileage increases for mileages up to 50,000 miles. For the vehicles tested at the ECS laboratory, the variance in the measurements for each

Attachment C

DETAILS ON THE STATISTICAL TESTS

INTRODUCTION

In this attachment we describe in detail the statistical tests used in this study to examine the effects of HiTEC 3000 on exhaust emissions. We describe all EPA statistical tests, SAI modifications to the EPA tests, and additional SAI tests. We also discuss the statistical assumptions underlying the analyses.

The EPA tests can be divided into four types: the initial emissions test, the adverse-effects tests based on the data as opposed to a fitted statistical model, the adverse-effects tests that are based on a regression fit to the data, and the cause-or-contribute test. The adverse-effects tests are intended to determine whether or not HiTEC 3000 has an adverse effect; the cause-or-contribute test is intended to determine whether any adverse effects detected will cause or contribute to failure to meet applicable emissions standards.

We first discuss the EPA nonregression tests and our modifications to those tests. These tests are based on assumptions of equal variances across mileages and equal variances across fuels for each model/pollutant combination. We show that the first assumption is tenable, but the data do not support the assumption of equal variances across fuels. Nevertheless, we give a mathematical proof that the failure of the latter assumption will not much affect the results of the statistical tests. We then describe the EPA rank sum test (equivalent to a Mann-Whitney Test) used for all of the nonregression comparisons. Finally, we describe the nonregression tests in detail: the initial emissions tests, the interval comparisons (e.g., 1k versus 5k test), and the integrated emissions test.

statistically significantly different for the two fuel groups for a given model and pollutant, assuming constancy of variance across intervals, as discussed above. Nevertheless, assuming constancy of variance across intervals, the result of the nine EPA tests and our modified versions are almost unchanged between the case when the assumption of equal variances is made and the case when the assumption of equal variances is not made, especially when results from all the vehicular models are combined into a single statistical test. Below we prove this result mathematically.

Comparison of Variances Across Fuels

We used the 50,000 mile data to estimate the test-to-test variance for each combination of model, fuel, and pollutant. For each model we compared the two variances using an F test. The data show that there is no consistent pattern in that the variances are sometimes lower for the EEE vehicles and are sometimes lower for the HiTEC 3000 vehicles. Further, the variances are in several cases statistically significantly different.

For this test we assume that all observations have the same variance for each model, fuel, and pollutant combination. We also assume that observations on the same vehicle at the same mileage interval have the same mean; this mean may vary across vehicles. Sample variances were computed from the observations at each mileage interval for each vehicle; and the degrees of freedom, one less than the number of emissions tests, were also calculated for each sample variance. The common variance was then estimated in the usual manner as a weighted average of the sample variances, using the degrees of freedom as weights. These pooled variance estimates are reported in Table C-1. In the final column of the table we report the results of F tests that test the hypothesis of equal variances against the alternative of unequal variances. This standard test requires the additional assumption that all observations are normally distributed. A five percent significance level was used.

The first point is that it is obvious from Table C-1 that the variances are not consistent across models. Furthermore, the table shows that the variances are different for each fuel but there is no consistent pattern. In particular the sign column shows that for CO and NO_x, four of the models have a higher HiTEC 3000 variance; for HC,

fuel group appears to increase at mileages beyond 50,000 miles. This effect is primarily due to the effects of using different testers with quite different positive and negative biases on measured emissions. Since in most cases the same tester was used for both tests on a given vehicle at a given mileage, much of the variability at higher mileages is due to variability between vehicles (due to variability amongst testers) rather than variability between emissions tests on the same vehicle. For the vehicles tested at the ATL laboratory the variability did not increase very much beyond 50,000 miles due to the wider variety of testers used throughout the testing program at ATL.

We conclude from this analysis that the assumption of constant variance across mileages is tenable for all the ATL data and at least the first 50,000 miles of the ECS data. This statement applies whether or not we assume equal means for each vehicle (at a given mileage) on a given fuel. Thus the assumption (approximation) of constant variance across mileages is reasonable for all the 50,000 mile analyses whether or not they are based on an equal car means assumption.

For the 75,000 mile data analyses the assumption of constant variances appears reasonable in cases where equal car means are not assumed. However, the assumption of constant variances appears to be more of an approximation for the cases where equal car means are assumed. Since it is not clear how best to objectively adjust the analyses of the 75,000 mile data to deal with the problem for the ECS data, we therefore chose to make the approximation that the assumption of equal variances across mileages (for a given model, fuel, and pollutant combination) holds for the complete mileage accumulation.

Assumptions of Equal Variances Across Fuels For Each Model/Pollutant

The majority of the modified EPA nonregression tests are based on the assumption that, for a given model and pollutant, the test-to-test variances are equal for each fuel. However, the results in this section show that in many cases the variances are

Table C-1b

Ethyl Corporation HiTEC 3000 Fleet Testing Program
 Estimated Variances
 50,000 Mile Analysis
 Data Set: ETHYL4S2, first 50,000 miles only
 Pollutant: Nitrogen Oxides

Model	Variance		Sign ^a	Significance Level (%) ^b
	EEE	HT3		
D	0.0010	0.0026	+	1.17*
E	0.0026	0.0013	-	3.52*
F	0.0014	0.0009	-	14.82
T	0.0014	0.0019	+	36.65
C	0.0028	0.0018	-	14.63
G	0.0013	0.0005	-	0.61*
H	0.0012	0.0012	+	95.93
I	0.0011	0.0022	+	3.19

^a Sign = "+" if the HiTEC 3000 variance is higher.

^b The lower the significance level, the greater the evidence of a difference in the variances for each fuel. Significant results at the 5 percent level are starred; for these models the assumption of equal variances is rejected.

Table C-1a

Ethyl Corporation HiTEC 3000 Fleet Testing Program
 Estimated Variances
 50,000 Mile Analysis
 Data Set: ETHYL4S2, first 50,000 miles only
 Pollutant: Hydrocarbons

Model	Variance		Sign ^a	Significance Level (%) ^b
	EEE	HT3		
D	0.0014	0.0016	+	80.72
E	0.0006	0.0003	-	1.88*
F	0.0019	0.0010	-	5.18
T	0.0005	0.0007	+	21.43
C	0.0002	0.0007	+	0.13*
G	0.0003	0.0002	-	10.54
H	0.0005	0.0005	-	85.13
I	0.0007	0.0005	-	23.81

^a Sign = "+" if the HiTEC 3000 variance is higher.

^b Significance level for the F test described in the text. The lower the significance level, the greater the evidence of a difference in the variances for each fuel. Significant results at the 5 percent level are starred; for these models the assumption of equal variances is rejected.

three of the models have a higher HiTEC 3000 variance. The reported significance levels show that half of the models have statistically significantly different variances for the two fuels for NO_x . For CO, only model C shows a statistically significant difference. For HC, two models show statistically significant differences at the five percent level; also, the difference is very nearly significant for model F. There is no pattern in the signs for the statistically significant results.

The conclusion from this analysis is that assumptions of equal variances across fuels are unsupported. However, we now show that most of the results of the statistical tests will be largely unaffected by assumptions of equal or unequal variances:

Proof of the Small Effect of the Equal/Unequal Variances Assumption

We now give a mathematical argument that failure of the assumption of equal variances across fuels for each pollutant and model group combination will not substantially affect the statistical results. The general argument for all nonregression tests follows. (The same proof can be applied to the linear and quadratic regression tests as described later.)

In each case the emissions are analyzed in terms of some linear model with an even number, $2k$, of parameters (k parameters for each fuel group). The emissions of a particular pollutant for a particular EEE vehicle at a given mileage are expressible as an error term plus a linear combination of the first k parameters; the coefficients depend on the pollutant, vehicle, and mileage. The error has mean zero and variance V (EEE). If the vehicle was replaced by a corresponding HiTEC 3000 vehicle of the same vehicular model, then the emissions of the same pollutant at the same mileage would be given by exactly the same linear combination of the second k parameters plus an error term with mean zero and variance V (HT3). In each case the statistical test is based on the estimated difference between a linear combination of the first k parameters and the same linear combination of the second k parameters.

For example, for the test for a single vehicular model of no difference in initial emissions assuming unequal car-means, the six parameters are the theoretical mean

Table C-1c

Ethyl Corporation HiTEC 3000 Fleet Testing Program
 Estimated Variances
 50,000 Mile Analysis
 Data Set: ETHYL4S2
 Pollutant: Carbon Monoxide

Model	Variance		Sign ^a	Significance Level (%) ^b
	EEE	HT3		
D	0.0692	0.0765	+	79.91
E	0.2353	0.1448	-	13.39
F	0.0281	0.0223	-	47.64
T	0.0824	0.1274	+	17.76
C	0.1182	0.3617	+	0.00*
G	0.0382	0.0317	-	56.53
H	0.1258	0.1259	+	99.84
I	0.1030	0.0829	-	49.15

^a Sign = "+" if the HiTEC 3000 variance is higher.

^b The lower the significance level, the greater the evidence of a difference in the variances for each fuel. Significant results at the 5 percent level are starred; for these models the assumption of equal variances is rejected.

$$V(\text{EEE}) = \text{SS}(\text{error EEE})/\text{DF}(\text{error EEE}) \quad (2)$$

and

$$V(\text{HT3}) = \text{SS}(\text{error HT3})/\text{DF}(\text{error HT3}) \quad (3)$$

where SS (error EEE) denotes the sum of the squared residuals (estimated errors) for the EEE data, DF (error EEE) denotes the "degrees of freedom" for the EEE errors (which depends entirely on the design matrix for the EEE data), and similarly for the HiTEC 3000 data (HT3). Thus in the unequal variance case the variance of the difference from Equation 1 is estimated by

$$C(\text{EEE}) \times \left\{ \frac{\text{SS}(\text{error EEE})}{\text{DF}(\text{error EEE})} + \frac{\text{SS}(\text{error HT3})}{\text{DF}(\text{error HT3})} \right\} \quad (4)$$

(on substituting Equations 2 and 3 into Equation 1). If equal variances are assumed for each fuel, then the error variances are estimated using the pooled estimate

$$V(\text{EEE}) = V(\text{HT3}) = \frac{\text{SS}(\text{error EEE}) + \text{SS}(\text{error HT3})}{\text{DF}(\text{error EEE}) + \text{DF}(\text{error HT3})} \quad (5)$$

(since the parameters used for the EEE statistical model and the HiTEC 3000 statistical model are distinct). Thus the variance of the difference formula (1) reduces to

$$2 \times C(\text{EEE}) \times \left[\frac{\text{SS}(\text{error EEE}) + \text{SS}(\text{error HT3})}{\text{DF}(\text{error EEE}) + \text{DF}(\text{error HT3})} \right] \quad (6)$$

in the equal variances case.

emissions at 1,000 miles for each of the three vehicles on each given fuel (data at other mileages or from other models is excluded). In this case k equals 3 and the mean emissions for a given vehicle is given by a linear combination of the three parameters (for that fuel group); the coefficients are 1 for the parameter corresponding to the given vehicle and 0 for the other two parameters. The statistical test is based on comparing the mean of the three theoretical means for the EEE vehicles and the corresponding mean of the three theoretical means for the HiTEC 3000 vehicles; the coefficients of the tested linear combinations used in this comparison are all one third.

An important point is that because the EEE and HiTEC 3000 parameters are distinct, and because the same test fuel was used on a given vehicle throughout the program, the estimated variances for the estimated linear combinations are of the form

$$\text{Variance (combination EEE)} = C(\text{EEE}) \times V(\text{EEE})$$

and similarly for HiTEC 3000. The values $C(\text{EEE})$ and $C(\text{HT3})$ depend on the design matrices, i.e., effectively the sets of test mileages, and on the linear combination tested.¹ Since the EEE and HiTEC 3000 test mileages were approximately equal, and since the same linear combination of unknown parameters is tested for each fuel, it follows that $C(\text{EEE})$ and $C(\text{HT3})$ will be approximately equal. The variance of the difference between the statistically independent linear combinations is therefore given by

$$C(\text{EEE}) \times [V(\text{EEE}) + V(\text{HT3})] \quad (1)$$

If unequal variances are assumed then the error variances are estimated by the mean square errors

¹ More precisely, if the coefficients of the linear combination are given by the vector c^T and if X is the appropriate design matrix in the standard formulation of the linear model, then

$$c(\text{EEE}) = c^T (X^T X)^{-1} c$$

Table C-2

Initial Emissions Rank Sum Test

Data Set: ETHYL4S2

Pollutant: CO

Model Group H

Emissions in Increasing Size (g/mi)	Car Number	Test Number	Fuel	Number of Smaller HiTEC 3000 Values
1.119	4	2	HiTEC 3000	
1.229	4	1	HiTEC 3000	
1.236	2	1	EEE	2
1.323	3	1	HiTEC 3000	
1.323	3	2	HiTEC 3000	
1.348	6	2	HiTEC 3000	
1.385	5	1	EEE	5
1.439	6	1	HiTEC 3000	
1.447	5	2	EEE	6
1.481	1	2	EEE	6
1.490	1	1	EEE	6
1.543	2	2	EEE	<u>6</u>
Rank Sum Test Statistic U				31

The fact that both fuel groups were tested at roughly the same set of test mileages means that C (EEE) approximately equals C (HT3) and DF (error EEE) approximately equals DF (error HT3). It follows that (4) and (6) are approximately equal.

This completes the argument that the results of the nonregression statistical tests will not be much affected by assumptions of equal or unequal variances across fuels. It should be noted, however, that the approximations used in this argument are relatively less valid for statistical tests based on relatively few data points, such as the nonregression tests for a single vehicular model. For this reason we have avoided making assumptions of equal variances across fuels for these statistical tests where possible.

Test Descriptions

Rank Sum Tests

The EPA based several of the non-regression tests on non-parametric rank sum tests for each vehicular model, which are equivalent to the Mann-Whitney or Wilcoxon tests. The EPA also combine the Mann-Whitney tests statistics for each vehicular model to obtain an overall rank sum test. In this section we describe these tests in detail using the example of the initial emissions test applied to the CO data for model group H.

The initial emissions test discussed in the next section includes a rank-sum test that compares the six observations at 1,000 miles for the EEE vehicles (two tests for each vehicle) and the six observations at 1,000 miles for the HiTEC 3000 vehicle to determine if there is a significant shift in the distribution between the two fuels. The test statistic is computed by counting the number of HiTEC 3000 observations smaller than each EEE observation and summing over the EEE observations. The calculation for the test statistic in the example is shown in Table C-2. The test statistic is 31.0. (To deal with the problem of ties, which does not happen for this particular example, each HiTEC 3000 observation exactly equal to the given EEE observation contributes 0.5 rather than one to the count, so that if there are two smaller values and three equal values then the count is $2 + 3 \times 0.5 = 3.5$).

Initial Emissions Tests

The purpose of the initial emissions test is to decide if the assumption of equal emissions levels at 1,000 miles (the mileage point at which HiTEC 3000 was introduced into half of the test fleet) was valid. The crucial issue is that if a significant initial difference is demonstrated then success or failure of some of the other statistical adverse effects tests or the cause or contribute test could simply be due to higher or lower initial emissions levels on the HiTEC 3000 vehicles compared to the EEE vehicles. Such an effect cannot be attributable to HiTEC 3000.

A two tailed statistical test is used to test the null hypothesis of no difference at 1,000 miles against the alternative of a difference (in either direction). The procedure used depends mainly upon whether or not the assumption of variability in car-means for a given model, fuel, and pollutant is made.

Equal Vehicle Effects

In the following set of statistical tests of the assumption of no difference between the two fuels at 1,000 miles, we assume that for a given model, fuel, and pollutant the true mean emissions are the same for all the emissions tests on each of the three vehicles. Thus each emissions test at 1,000 miles is weighted equally. In order to make as few assumptions as possible we have not assumed the equality of variances across fuels.

The EPA sign test of the assumption of no difference between the two fuels at 1,000 miles is based on comparing the sample means of all 1,000 miles emissions tests on a given model for the two fuels. The EPA rank sum test was described in the previous section. For a given model the ranks of the six emissions tests using HiTEC 3000 were compared with the ranks of the six emissions tests using EEE.

A more powerful statistical test of the difference in the means at 1000 miles is the Smith-Satterthwaite t test, which is a modification of the simple t test to account

If the initial emissions levels of EEE and HiTEC 3000 vehicles had the same statistical distributions then the mean value of the test statistic would be 18, since on average three HiTEC 3000 observations will be smaller than each EEE observation. In general, if there are m EEE observations and n HiTEC 3000 observations, then the mean and variance of the test statistic U are given by the standard formulae

$$E(U) = mn/2, \text{ and}$$

$$\text{Var}(U) = mn(m+n+1)/12.$$

The difference between the test statistic and the mean is $31 - 18 = 13$, so that the same or greater evidence against the hypothesis of equal distributions would be found had the test statistic been greater than or equal to 31 or less than or equal to $18 - 13 = 5$. The observed significance level is given in standard tables (for these small sample sizes) as 0.042, or 4.2 percent, since 0.021 is the probability of obtaining a value of at most 5 under the null hypothesis of equal distributions. (Had there been ties then the test statistic could have had fractional values; such values are rounded down for calculating the observed significance level.) Note also that standard table values were only used for the important cases $m = n = 3$; $m = n = 6$; $m = 2, n = 3$; $m = 4, n = 6$. In other cases the significance levels were estimated by the normal approximation (that assumes a normal distribution for the test statistic).

To combine the results from all the models the EPA used the test statistic given by the sum across models of the values of U . Since each U statistic is independent the mean and variance of the sum are given by the sums of the means and variances for each model. Furthermore, a reasonable approximation, used previously by the EPA, is to assume that the overall rank sum test statistic is approximately normally distributed, so that observed significance values are easily estimated (the assumption of normality is more tenable for the overall test statistic than for the test statistics for each model since the overall test statistic is expressible as the sum of eight times as many independent values).

Unequal Vehicle Effects

In this case we do not assume the equality of car means for each model, fuel, pollutant combination. It is appropriate in this case to estimate the mean of the car-means rather than the mean of all the emissions tests. Thus for each vehicle the true mean 1,000 mile emissions is estimated by averaging across emissions tests for the vehicle and the true mean of the car-means is estimated by averaging the three car-means.

First, a simple sign test comparing the eight differences in the means of the car-means for each model is carried out. Then a more powerful t test, based on dividing the difference by its standard error in a manner similar to the equal vehicle effects analysis, is carried out. In this case the standard error is more complicated since we do not assume equality of car-means but do assume equality of test-to-test variance across fuels.

For purposes of explanation, assume that vehicles 1, 2, and 3 were tested using HiTEC 3000, and vehicles 4, 5, and 6 were tested using EEE. Let X_{ij} denote the emissions for the jth 1,000 mile emissions test for vehicle i. Let n_i denote the number of tests on vehicle i.* Then the car-mean for vehicle i is given by

$$\bar{X}_i = \sum_{j=1}^{n_i} X_{ij} / n_i \quad (9)$$

The mean of the car-means for the HiTEC 3000 vehicles is

$$M_H = \frac{\bar{X}_1 + \bar{X}_2 + \bar{X}_3}{3} \quad (10)$$

* The number of tests n_i is nearly always two except when there are unscheduled maintenance tests.

for the non-assumption of equal variances for the two populations (fuels). The test statistic is the difference between the two sample means divided by the standard error of the difference.

Assume that the number of tests, mean, and sample variance for the EEE vehicles of a given model were $N(EEE)$, $\text{Mean}(EEE)$, and $\text{Variance}(EEE)$ respectively. Similarly for HiTEC 3000. Then the standard error of the difference is the maximum likelihood estimate

$$s.e. = \left[\frac{\text{Variance}(EEE)}{N(EEE)} + \frac{\text{Variance}(HT3)}{N(HT3)} \right]^{\frac{1}{2}} \quad (7)$$

The test statistic T is therefore $T = \frac{\text{Mean}(HT3) - \text{Mean}(EEE)}{s.e.}$

The Smith-Satterthwaite test makes the approximation that this test statistic has a Student's t distribution with the random number of degrees of freedom:

$$d.f. = \frac{\frac{\text{Variance}(EEE)^2}{N(EEE)} + \frac{\text{Variance}(HT3)^2}{N(HT3)}}{\frac{\text{Variance}(EEE)^2}{N(EEE)^2 [N(EEE) - 1]} + \frac{\text{Variance}(HT3)^2}{N(HT3)^2 [N(HT3) - 1]}} \quad (8)$$

Thus the significance level of the observed difference in initial means is found by comparing the test statistic with the percentiles of the "random" t distribution.

The weighted average test weights the model mean differences by sales to give a weighted mean difference. The variance of the weighted mean difference is therefore estimated by the sum over vehicular models of the model weight squared times the variance of the model mean difference given by the square of Equation 7. The weighted mean difference is divided by the square root of its estimated variance and compared with a standard normal distribution.

The t statistic is the difference D (Eq. 11) divided by its estimated standard error (the square root of Equation 14 after applying Equation 15). Since the degrees of freedom for vehicle i is $n_i - 1$, the degrees of freedom for the t statistic is given by the sum

$$\sum_{i=1}^6 (n_i - 1) \quad (16)$$

Finally, a weighted average test using the differences (Eq. 11) and variance estimates (Eq. 14) with (Eq. 15) for each model is carried out as described in the previous subsection on equal vehicle effects.

1K Versus 5K Tests and Other Interval Comparisons

In this section we describe the statistical tests comparing the increases from 1,000 miles to 5,000 miles for the two fuels. The main idea is that if the average increase in emissions from 1,000 to 5,000 miles is significantly larger for the HiTEC 3000 vehicles, then the waiver fuel can be said to have an adverse effect on emissions over the 4,000 mile interval. As for the initial emissions tests, the statistical procedure used depends on whether or not an assumption of equal vehicle effects is made; such an assumption for this statistical analysis requires that the true mean increases for each vehicle in the same model and fuel group are equal.

Analogous statistical tests were used for other comparisons such as the 1K versus 75K tests which compare the mean changes in emissions from 1,000 to 75,000 miles.

Equal Vehicle Effects

In this subsection we assume that the average increase in emissions from 1,000 to 5,000 miles is the same for each model, fuel, and pollutant combination (thus for the three vehicles involved) but the variances are different for each fuel. Thus the three increases in mean emissions for the EEE vehicles of a given model come from the same statistical distribution; similar assumptions are made for the HiTEC 3000 vehicles.

and the difference D in the mean of the car-means is

$$D = \frac{\bar{X}_1 + \bar{X}_2 + \bar{X}_3}{3} - \frac{\bar{X}_4 + \bar{X}_5 + \bar{X}_6}{3} \quad (11)$$

If σ^2 denotes the variance of each emissions test, assumed equal for each fuel, then the variances of the statistics in Equations 9 to 11 are given respectively by Equations 12 to 14:

$$\text{Var}(\bar{X}_i) = \sigma^2/n_i \quad (12)$$

$$\text{Var}(M_H) = \frac{1}{n_1} + \frac{1}{n_2} + \frac{1}{n_3} \frac{\sigma^2}{9} \quad (13)$$

$$\text{Var}(D) = \frac{1}{n_1} + \frac{1}{n_2} + \frac{1}{n_3} + \frac{1}{n_4} + \frac{1}{n_5} + \frac{1}{n_6} \frac{\sigma^2}{9} \quad (14)$$

Pooling the six within-vehicle variance estimates gives the following estimate of the common variance:

$$\sigma^2 = \frac{\sum_{i=1}^6 \sum_{j=1}^{n_i} X_{ij}^2 - \bar{X}_i^2}{\sum_{i=1}^6 (n_i - 1)} \quad (15)$$

A more powerful test uses all the individual emissions tests results for the given vehicular model and pollutant at 1,000 and 5,000 miles. For a given model assume that vehicles 1, 2, and 3 are fueled with Hitec 3000. Let α_i be the true mean emissions at 1,000 miles and β_i be the true mean emissions at 5,000 miles, for vehicle i . The statistical model assumes that the observed emissions for each emissions test at 1,000 or 5,000 miles are given by the appropriate true mean emissions parameter (either an α or a β) plus a random error. The random errors have the same unknown variance σ^2 .

The parameter of interest is the mean of the increases in the means for the HiTEC 3000 vehicles less the mean of the increases in the means for the EEE vehicles, i.e.

$$\frac{(\beta_1 - \alpha_1) + (\beta_2 - \alpha_2) + (\beta_3 - \alpha_3)}{3} - \frac{(\beta_4 - \alpha_4) + (\beta_5 - \alpha_5) + (\beta_6 - \alpha_6)}{3} \quad (17)$$

The parameter in Equation 17 is estimated by the observed difference in the mean increases, i.e., the test statistic used in the above sign test. Equivalently, the estimate is obtained by replacing each α_i or β_i in Equation 17 by the corresponding sample mean of emissions tests (usually two). The variance of the estimate is computed similarly to Equations 12 to 14 of the previous section. In particular, if exactly two emissions tests were carried out for each vehicle, mileage interval combination, then the variance of the estimate is given by

$$\left(\frac{1}{3}\right)^2 \frac{\sigma^2}{2} \quad (18)$$

assuming independence of consecutive emissions tests. The unknown test-to-test variance σ^2 is estimated analogously to Equation 15 by taking a weighted average of the 12 sample variances for the 12 vehicle, mileage interval combinations; the weights are the degrees of freedom, one less than the number of emissions tests. In

The EPA sign test of the hypothesis of no difference in mean increases for the two fuels is based on comparing the sample means of the mean increases for the EEE and HiTEC 3000 vehicles. Thus for each vehicle we subtract the mean at 1,000 miles from the mean at 5,000 miles and then average across vehicles for each fuel and model. The EPA rank sum test is carried out in a similar manner to the procedure for the initial emissions test. In this case the rank sum test is based on comparing the ranks of the three mean increases for the EEE vehicles with the ranks of the three mean increases for the HiTEC 3000 vehicles. The individual emissions tests results are not used directly.

As a more powerful test of the hypothesis of equal mean increases, assuming that the variances of the increases for the two fuels are unequal, we also carried out a Smith-Satterthwaite test as described for the initial emissions test, equal vehicle effects case. The test statistic is the difference in the mean increases for the two fuels divided by the standard error of the difference. Equation 7 is a formula for the standard error, while Equation 8 gives the degrees of freedom for the approximate t test. Note that in this case the sample variances are based on only three observations (three mean increases) whereas for the initial emissions test all six 1,000 mile emissions tests were used for each fuel and model. A weighted average test weighting models by sales is carried out in a similar manner to the procedure for the initial emissions test.

Unequal Vehicle Effects

In this case we do not assume that the mean increases for the three vehicles of a given model on a given fuel have the same true mean. However we do assume that the six car-mean increases for a given model have the same variance.

First we use the sample mean of the three increases (i.e., mean emissions at 5,000 miles less mean emissions at 1,000 miles) for a given model, fuel, pollutant combination to estimate the true mean increase for that combination. We carry out a simple sign test using the differences in the increases for the eight models. This sign test is identical to the sign test for the equal vehicle effects case.

interval is found by dividing by the accumulated mileage $x_{11} - x_1$. The increase over the initial emissions rate is then found by subtracting the initial rate (y_1).

The three increases for each fuel (for a given model and pollutant) were compared in a similar manner to the 1K versus 5K test using the EPA rank sum test and the mean increases across fuels for the eight models were compared using a sign test. Assuming that the three increases for each fuel come from the same statistical distribution (with equal variances across fuels) the difference in the mean increases was also tested using a standard pooled t test. Thus if the sample variance of the increases for the three EEE vehicles is $S^2(\text{EEE})$, and is $S^2(\text{HT3})$ for the three HiTEC 3000 vehicles, then the pooled estimate of the variance of the difference in the two mean increases for each fuel is

$$\left[\frac{S^2(\text{EEE}) + S^2(\text{HT3})}{2} \right] \left(\frac{1}{3} + \frac{1}{3} \right) \quad (20)$$

The difference in the mean increases is divided by the square root of Equation 20 to give a t statistic which is compared with the percentiles of a t distribution with 4 degrees of freedom. The weighted average z test is carried out analogously to the initial emissions test, using the pooled variance estimates (Eq. 20) for the eight models.

REGRESSION BASED TESTS

Regression Assumptions

In this section we shall describe and discuss the statistical assumptions used in fitting both the linear and quadratic models used in some of the EPA tests and our modified versions of those tests.

the case of two emissions tests per combination the estimated test-to-test variance reduces to the unweighted mean of the 12 sample variances.

The test statistic for each vehicular model is then computed by dividing the estimate of the parameter in Equation 17 by the square root of Equation 18, replacing σ^2 by its estimate. The degrees of freedom for the t test is the total of the degrees of freedom for the 12 vehicle, mileage interval combinations.

The weighted average z test is carried out analogously to the procedures for the initial emissions test.

Integrated Emissions Test

The idea of the integrated emissions test described in this subsection is to compare for each fuel the additional long-term emissions above the initial (1,000 mile) emissions rate. These increases are estimated using the areas under the emissions curves. The HiTEC 3000 fuel will fail this test if the increases are significantly higher on average for the HiTEC 3000 vehicles.

We describe the procedure for the 50,000 mile analysis; the 75,000 mile analysis is an obvious modification. For each vehicle the total emissions from 1,000 miles to 50,000 miles was estimated by integrating under the observed emissions curve. More precisely, for each mileage interval, the mean test mileage and the mean emissions was computed for that vehicle and a polygonal curve drawn through the 11 points. The area was found using the trapezoidal rule, i.e., if the points are (x_i, y_i) then the total area is given by

$$\sum_{i=1}^{10} (x_{i+1} - x_i) \left(\frac{y_i + y_{i+1}}{2} \right) \quad (19)$$

Equation 19 estimates the total emissions between x_1 and x_{11} miles (approximately 1,000 to 50,000 miles) for that vehicle. Thus the mean emissions rate over that

model may not be the best regression fit to the data, and that higher-order regression models, which allow for curvature, might perform better. We discuss the use of higher-order regressions in a later section.

Quadratic Regression

Because of the observed nonlinearities we also fit a quadratic regression model to the data. In this case the emissions are given by a quadratic function of mileage plus a random error. Although the fit of the quadratic models is superior to the fit of the linear models, many of the comments in the previous subsection apply to this case also. We will make the same assumption (approximation) that the regression error variances are constant across mileages for each vehicle model, fuel, and pollutant combination.

Assumptions of Equal Variances Across Fuels for Each Model/Pollutant

In our discussion of the nonregression tests we showed that the data do not support the assumption that the test-to-test variances are equal across fuels for each model/pollutant combination. We also gave a mathematical argument to show that failure of this assumption does not much change the results of the statistical comparisons. Under the assumptions of the regression models, the same conclusions apply to the regression error variances and the corresponding effect on the results of the regression based statistical tests. This is because the same general proof applies for the regression based tests.

As an example, we can consider the linear regression slopes test described in greater detail below. For a particular vehicular model and pollutant, the statistical model fits a slope and intercept parameter for each fuel. The test is based on the linear combinations of one times the slope and zero times the intercept, for each fuel. To apply the general argument based on Equations 1 to 6: The appropriate "combination" is the slope parameter; the degrees of freedom parameter $DF(\text{error } EEE)$ equals $N(EEE) - 2$, where $N(EEE)$ is the number of emissions tests performed on the EEE vehicles; the variance coefficient $C(EEE)$ reduces to

Linear Regression

In all of the linear regression tests a simple regression line with an intercept and slope is fitted separately to each combination of model, fuel, and pollutant. Thus we assume that the emissions are given by a straight line function of mileage plus a random error. The weighted average regression line fitted to each fuel and pollutant is computed by taking weighted averages (for both slope and intercept) across models, with weights proportional to 1988 sales figures. (A simple unweighted average would only estimate the emissions for a vehicle selected at random from Ethyl's stratified sample.)

In order to fit the regression lines we are implicitly assuming the constancy of error variances across mileages, as discussed in the next paragraph. Since both slope and intercept parameters vary by fuel, the lines are fitted separately for each fuel and so are unaffected by assumptions of constancy or lack of constancy of variance across fuels. As discussed in the next subsection, such choices will (slightly) affect the results of the fuel comparisons.

We assume that the errors about the true regression line are normally distributed with mean zero and a constant variance (for each model, pollutant and fuel). Thus we are effectively assuming that the regression error variability does not increase with emissions (since, generally, emissions increase with mileage). In our discussion of the assumptions used in the nonregression tests we discussed the emission test variability and argued that the test-to-test variability is independent of mileage. However, here we are considering the variability about the regression line, which is a different issue. The two types of variability will be comparable only if the linear regression model is a good statistical model for the data.

A comparison between the data plots and the fitted regression lines shows that the magnitudes of the residuals from the fitted regression lines (differences between the observations and the values predicted from the regression model) do not show any obvious patterns but the residuals are consistently negative at lower mileages. This corresponds to the fact that the fitted regression lines tend to overestimate the emissions at the lower mileages. The implication is that the simple linear regression

$$\text{Intercept (EEE)} = \frac{\sum \text{EEE}_i - \text{Slope(EEE)} \sum \text{miles}_i}{N(\text{EEE})} \quad (22)$$

$$\text{SS (error EEE)} = \sum [\text{EEE}_i - \text{Intercept(EEE)} - \text{miles}_i \text{ Slope(EEE)}]^2 \quad (23)$$

$$\text{SS (miles EEE)} = \sum (\text{miles}_i)^2 - (\sum \text{miles}_i)^2 / N(\text{EEE}) \quad (24)$$

$$\text{Variance (slope EEE)} = \frac{1}{\text{SS(miles EEE)}} \times V(\text{EEE}) \quad (25)$$

$$\text{Variance (intercept EEE)} = \frac{\sum (\text{miles}_i)^2 / N(\text{EEE})}{\text{SS(miles EEE)}} \times V(\text{EEE}) \quad (26)$$

$$\text{Covariance (slope EEE, intercept EEE)} = \frac{- \sum \text{miles}_i / N(\text{EEE})}{\text{SS(miles EEE)}} \times V(\text{EEE}) \quad (27)$$

where $V(\text{EEE})$ is the unknown variance for the EEE observations. Formulae for the HiTEC 3000 regression lines are analogous.

In all of our analyses we assume equal variances across fuels and use an unbiased estimate of the unknown variance; the unknown variance $V(\text{EEE})$ is then estimated by substituting the pooled estimate

$$C(EEE) = \frac{1}{(N(EEE) - 2) \text{ variance}}$$

(see Equation 25 below), where "variance" is the sample variance of the test mileages for all the EEE emissions tests. Similar formulae apply for the HiTEC 3000 regression.

Note that the general proof can be applied to the deterioration factor test even though the deterioration factor is not a linear combination of the regression parameters. This is because the "delta method" used in estimating the variance of the deterioration factor is based on making a linear approximation for the deterioration factor. Thus the general proof applies to that linear approximation.

General Discussion of Linear and Quadratic Regressions

Regression Formulae

Linear Regression: Formulae for Slope, Intercept, Sums of Squares, Variances and Covariance

Some of the original EPA tests are based on fitting a simple linear regression model that assumes a straight line relationship between mean emissions and mileage (a different straight line for each model, fuel, and pollutant combination). For convenience we list standard formulae for the regression coefficients (slope and intercept) and their variances and covariances. These formulae are available in most statistics textbooks.

Let the pairs EEE_i and $miles_i$ for i between 1 and $N(EEE)$ represent the emissions EEE_i at the test mileage $miles_i$ for all the tests on EEE vehicles of a given model. Then

$$\text{Slope (EEE)} = \frac{\sum miles_i EEE_i - \sum miles_i \sum EEE_i / N(EEE)}{\sum (miles_i)^2 - (\sum miles_i)^2 / N(EEE)} \quad (21)$$

$$V (EEE, \text{pooled}) = V (HT3, \text{pooled})$$

$$= \frac{SS(\text{error } EEE) + SS(\text{error } HT3)}{[N(EEE) - 2] + [N(HT3) - 2]} \quad (28)$$

For the maximum percentage of vehicles failing standard test and the cause or contribute test we make the same assumption about equal variances but instead use a maximum likelihood estimate. Statistical theory suggests that this estimate has better performance than the pooled estimate when functions of all the unknown parameters (slope, intercept, and variance) are estimated. That the usual pooled variance estimate is unbiased does not imply that nonlinear functions of the variance estimate are also unbiased. The maximum likelihood estimate of each parameter has the advantage of consistency and asymptotic efficiency and these useful properties also extend to most nonlinear functions of the maximum likelihood estimates. The maximum likelihood estimate (mle) is

$$V (EEE, \text{mle}) = V (HT3, \text{mle})$$

$$= \frac{SS(\text{error } EEE) + SS(\text{error } HT3)}{N(EEE) + N(HT3)} \quad (29)$$

The difference between the variance estimates in Equations 28 and 29 is small for the large data sets analyzed.

Quadratic Regression

The quadratic regression model expresses mean pollutant concentration as the sum of three terms: an intercept, a slope coefficient multiplied by mileage, and a quadratic coefficient multiplied by mileage squared. Formulae for the intercept, slope coefficient, and quadratic coefficient and the variance covariance matrix may be found in standard regression texts.

Comparison of Linear and Quadratic Regression Models

In this section we discuss the fit of the linear and quadratic regression models to the data. The main result is that for most combinations of vehicular model, fuel and pollutant, the quadratic model fits statistically significantly better than the linear model. This holds for both the 50,000 and the 75,000 mile data.

For each model, fuel, and pollutant combination we fitted both linear and quadratic regressions to the data and computed the R-squared statistics. The R-squared statistic is a number between 0 and 1 that measures the goodness of fit of the regression model. R-squared values close to 1 occur when the fit of the regression line or curve is almost exact. It can also be interpreted as the proportion of the variation in emissions explained by the regression model. Mathematically, the R-squared statistic can be calculated as the square of the correlation coefficient between the data and the predicted values. Alternatively, the R-squared statistic can be computed as 1 minus the ratio of the error sum of squares to the corrected total sum of squares; for linear regression the error sum of squares is given in Equation 23, and the corrected total sum of squares is the sample variance of the emissions multiplied by the degrees of freedom.

R-squared statistics for linear and quadratic regressions for all three pollutants for the 50,000 mile data are reported in Table C-3; the results for the 75,000 mile data are reported in Table C-4. Since the linear model is a special case of the quadratic model, the R-squared statistics for the quadratic models are by definition higher. In the final column we note cases for which the improved fit is statistically significant.

The improvement in fit for the quadratic regression model over the linear regression model is tested in two mathematically equivalent ways. In terms of the R-squared statistics a two tailed t test can be based on the equation

$$t^2 = \frac{(N - 3) (R_{\text{quad}}^2 - R_{\text{lin}}^2)}{(1 - R_{\text{quad}}^2)}$$

Table C-3a

R-Squared Statistics for Linear and Quadratic Regressions
 50,000 Mile Analysis
 Data Set ETHYL4S2
 Pollutant HC

Model Group	Fuel	R-Squared		Significant Improvement
		Linear	Quadratic	
D	EEE	0.85	0.87	x
D	HT3	0.81	0.84	x
E	EEE	0.47	0.47	
E	HT3	0.34	0.51	x
F	EEE	0.86	0.87	x
F	HT3	0.87	0.91	x
T	EEE	0.82	0.83	x
T	HT3	0.82	0.82	
C	EEE	0.27	0.38	x
C	HT3	0.36	0.53	x
G	EEE	0.20	0.36	x
G	HT3	0.38	0.65	x
H	EEE	0.70	0.73	x
H	HT3	0.58	0.59	
I	EEE	0.02	0.04	
I	HT3	0.10	0.15	x

Table C-3b

R-Squared Statistics for Linear and Quadratic Regressions
 50,000 Mile Analysis
 Data Set ETHYL4S2
 Pollutant NOx

Model Group	Fuel	R-Squared		Significant Improvement
		Linear	Quadratic	
D	EEE	0.37	0.55	x
D	HT3	0.28	0.57	x
E	EEE	0.46	0.47	
E	HT3	0.63	0.69	x
F	EEE	0.53	0.54	
F	HT3	0.19	0.21	
T	EEE	0.03	0.03	
T	HT3	0.01	0.27	x
C	EEE	0.46	0.46	
C	HT3	0.17	0.22	x
G	EEE	0.26	0.67	x
G	HT3	0.30	0.73	x
H	EEE	0.05	0.06	
H	HT3	0.04	0.07	
I	EEE	0.18	0.25	x
I	HT3	0.09	0.21	x

Table C-3c

R-Squared Statistics for Linear and Quadratic Regressions
 50,000 Mile Analysis
 Data Set ETHYL4S2
 Pollutant CO

Model Group	Fuel	R-Squared		Significant Improvement
		Linear	Quadratic	
D	EEE	0.91	0.91	
D	HT3	0.89	0.89	
E	EEE	0.78	0.78	
E	HT3	0.58	0.65	x
F	EEE	0.82	0.82	
F	HT3	0.68	0.68	
T	EEE	0.82	0.82	
T	HT3	0.80	0.80	
C	EEE	0.38	0.51	x
C	HT3	0.39	0.46	x
G	EEE	0.40	0.49	x
G	HT3	0.42	0.71	x
H	EEE	0.80	0.85	x
H	HT3	0.74	0.76	x
I	EEE	0.37	0.43	x
I	HT3	0.18	0.27	x

Table C-4a

R-Squared Statistics for Linear and Quadratic Regressions
 75,000 Mile Analysis
 Data Set ETHYL4S2
 Pollutant HC

Model Group	Fuel	R-Squared		Significant Improvement
		Linear	Quadratic	
D	EEE	0.73	0.80	x
D	HT3	0.53	0.75	x
E	EEE	0.39	0.39	
E	HT3	0.50	0.52	x
F	EEE	0.49	0.80	x
F	HT3	0.64	0.84	x
T	EEE	0.66	0.70	x
T	HT3	0.53	0.73	x
C	EEE	0.26	0.31	x
C	HT3	0.18	0.33	x
G	EEE	0.27	0.28	
G	HT3	0.32	0.41	x
H	EEE	0.75	0.76	x
H	HT3	0.67	0.67	
I	EEE	0.03	0.04	
I	HT3	0.12	0.13	

Table C-4b

R-Squared Statistics for Linear and Quadratic Regressions
 75,000 Mile Analysis
 Data Set ETHYL4S2
 Pollutant NOx

Model Group	Fuel	R-Squared		Significant Improvement
		Linear	Quadratic	
D	EEE	0.01	0.28	x
D	HT3	0.01	0.31	x
E	EEE	0.56	0.58	x
E	HT3	0.58	0.67	x
F	EEE	0.60	0.62	x
F	HT3	0.34	0.35	
T	EEE	0.10	0.16	x
T	HT3	0.22	0.28	x
C	EEE	0.59	0.60	
C	HT3	0.38	0.38	
G	EEE	0.31	0.36	x
G	HT3	0.29	0.40	x
H	EEE	0.07	0.08	
H	HT3	0.22	0.24	
I	EEE	0.30	0.31	
I	HT3	0.03	0.04	

Table C-4c

R-Squared Statistics for Linear and Quadratic Regressions
 75,000 Mile Analysis
 Data Set ETHYL4S2
 Pollutant CO

Model Group	Fuel	R-Squared		Significant Improvement
		Linear	Quadratic	
D	EEE	0.76	0.81	x
D	HT3	0.71	0.78	x
E	EEE	0.70	0.73	x
E	HT3	0.48	0.57	x
F	EEE	0.71	0.73	x
F	HT3	0.62	0.64	x
T	EEE	0.68	0.69	x
T	HT3	0.60	0.66	x
C	EEE	0.19	0.34	x
C	HT3	0.19	0.33	x
G	EEE	0.34	0.44	x
G	HT3	0.51	0.58	x
H	EEE	0.65	0.79	x
H	HT3	0.69	0.79	x
I	EEE	0.31	0.33	
I	HT3	0.13	0.17	x

where N denotes the number of observations for the given model, fuel combination. The test statistic t has a t distribution with $N - 3$ degrees of freedom if the linear model is correct. An equivalent calculation of t is based on dividing the estimated quadratic coefficient from the quadratic regression by an estimate of its standard deviation as can be found in standard regression texts. The test for significant improvement in Tables C-3 and C-4 is made at the 5 percent level.

For the 50,000 mile data a general pattern is that the fit of the linear model is best for CO and is quite poor for NO_x . The worse linear fits for HC are for model groups C, G and I. For CO, model group I fits the linear model relatively poorly. For NO_x the worse of the generally poor linear fits is for model groups T and H, which show almost no correlations between emissions and mileage. For the quadratic model almost the same remarks apply except that for NO_x there are substantial improvements in the regression fit in several cases; in particular, the R-squared statistic for model T on HiTEC 3000 increased from 0.01 (for linear regression) to 0.27 (for quadratic regression), and the improvements in fit for model G are from 0.3 to 0.7 for both fuels. However the best of the quadratic regression R-squared statistics for NO_x is only 0.73 and several other cases fit substantially worse than that. Thus for NO_x both linear and quadratic regression models leave unexplained a substantial fraction of the variation in emissions. For each pollutant the quadratic model fits statistically significantly better in the majority of cases for each pollutant. Note that although the improvement is statistically significant in more cases for HC than for CO or NO_x , the size of the improvement is typically larger for the NO_x cases. For example, for model D on EEE, the improvement in R-squared value is from 0.85 to 0.87 for HC but from 0.37 to 0.55 for NO_x .

Table C-4 shows the R-squared comparisons for the 75,000 mile data. The general pattern and conclusions are essentially the same as for the 50,000 mile data. However, an important feature is that the fit of both regression models is noticeably poorer for the 75,000 data compared to the 50,000 mile data, but the improvements in fit for the quadratic model are noticeably larger (and statistically more significant). For CO the improvement is statistically significant in every case but one.

Test Descriptions

Slopes and Quadratic Coefficient Tests

The statistical tests described in this section and in the following sections are all based on regression models. For the linear regression tests the mean emissions are assumed to increase (or decrease) linearly with mileage with a constant slope, i.e., deterioration rate. For the quadratic model the mean emissions are assumed to follow a quadratic curve against mileage and hence the slope is assumed to vary with mileage; both the raw data and the fitted quadratic models generally show that the deterioration rate decreases with mileage for both fuels.

Under the assumptions of the regression models, regardless of initial emissions levels, the fuel with the higher deterioration rate (slope) is arguably the fuel with the more adverse effect. Thus in the statistical tests in this section we compare slopes to determine if the HiTEC 3000 slope is statistically significantly higher than the EEE slope. For the linear regression model the result is the same at every mileage. For the quadratic model the variation of slope with mileage means that the result of the test can vary with different mileages reflecting the possibility that the HiTEC 3000 effect might vary by mileage.

For the quadratic regression model the deterioration rate varies with mileage at a rate depending only on the quadratic coefficient. If the quadratic coefficient for HiTEC 3000 is higher than for EEE then the deterioration rate for HiTEC 3000 increases more rapidly, which would indicate an adverse effect. We therefore describe in this section a statistical test based on comparing the quadratic coefficients.

In each case a simple sign test is performed based on comparing the results for the two fuels for the eight models. In this description we focus on more powerful statistical tests of the differences in the slopes and quadratic coefficients for each model.

Linear Regression

Consider a fixed model and pollutant. The linear regression slopes test is based on the difference between the fitted regression slopes for the two fuels. The slopes are given by Equation 21 for EEE, and similarly for HiTEC 3000. Using the independence of the EEE and HiTEC 3000 observations it follows from Equation 25 that the variance of the slope difference Slope (HT3) minus Slope (EEE) is given by

$$\text{Variance (Slope difference)} = \frac{V(\text{EEE})}{SS(\text{miles EEE})} + \frac{V(\text{HT3})}{SS(\text{miles HT3})} \quad (30)$$

The standard error of the slope difference is the square root of Equation 30. Under the assumption of equal variances across fuels, the error variances $V(\text{EEE})$ and $V(\text{HT3})$ for each fuel are estimated by the pooled variance in Equation 28 which reduces Equation 30 to Equation 31:

$$\left[\frac{SS(\text{error EEE}) + SS(\text{error HT3})}{N(\text{EEE}) + N(\text{HT3}) - 4} \right] \left[\frac{1}{SS(\text{miles EEE})} + \frac{1}{SS(\text{miles HT3})} \right] \quad (31)$$

The test statistic for the difference in the linear regression slopes is the slope difference divided by its standard error (the square root of Equation 31). This is compared with a t distribution on $N(\text{EEE}) + N(\text{HT3}) - 4$ degrees of freedom.

The tests based on weighted averages across models (for each pollutant) are analogous to the procedure for the initial emissions test. The estimated slope differences for the eight models are weighted by 1988 sales in order to estimate the average slope difference, and then appropriately weighted sums of the estimated variances of the slope differences (Equation 31) are used to estimate the variance of the weighted average slope difference. The average slope difference divided by its estimated standard deviation is compared with a standard normal distribution.

Quadratic Regression

For a fixed vehicular model, fuel, and pollutant, let a , b , and c denote the estimated intercept, slope, and quadratic coefficient for the quadratic regression model. Thus the estimated mean emissions at mileage m are $a + bm + cm^2$. Denote the estimated variances of the estimates by $\text{Var}(a)$, $\text{Var}(b)$, and $\text{Var}(c)$, and the covariances by $\text{Cov}(a,b)$, etc. Just as for the linear regression model, the variance and covariance estimates use a pooled error variance estimate since equal error variances are assumed across fuels. For the quadratic model the pooled error variance estimate from Equation 28 is replaced by

$$\frac{SS(\text{error EEE}) + SS(\text{error HT3})}{[N(\text{EEE}) - 3] + [N(\text{HT3}) - 3]} \quad (32)$$

where $SS(\text{error EEE})$ and $SS(\text{error HT3})$ are defined analogous to Equation 23.

For the quadratic model the slope varies with mileage. In particular, the slope at 25,000 miles is given by

$$b + 2c(25000) = b + 50000c \quad (33)$$

The variance of the slope in Equation 33 is therefore estimated by

$$\text{Var}(b) + 50000^2 \text{Var}(c) + 2(50000) \text{Cov}(b, c) \quad (34)$$

Thus the difference in slopes at 25,000 miles has a variance given by the sums of Equation 34 for the two fuels. The t test of slopes at 25,000 miles is based on the slope difference divided by the square root of the estimated variance of the difference. The degrees of freedom for the t test is $N(\text{EEE}) + N(\text{HT3}) - 6$. The calculations are similar for slopes comparisons at other mileages.

The quadratic coefficient c is also one half of the rate of change of the fitted slope. Thus a t test of the difference in the quadratic coefficients for the two fuels is used to determine if the rate of change of the HiTEC 3000 slope is significantly greater than the rate of change of the EEE slope. The difference in the estimates of c has a variance given by the sum of the $\text{Var}(c)$ values for the two fuels. The t test is based on the difference divided by the square root of its variance. As in the slopes test, the degrees of freedom is $N(\text{EEE}) + N(\text{HT3}) - 6$.

Finally, both of these quadratic regression tests were applied to give overall results, weighting models by 1988 sales figures. The method is analogous to the non-regression tests and the linear regression slopes test.

Deterioration Factors Test

The deterioration factor used by the EPA in certification testing is based on the ratio of estimated emissions at 50,000 miles to estimated emissions at 4,000 miles. The deterioration factor is used to multiply emissions for vehicles tested at low mileages only in order to estimate emissions at 50,000 miles, for comparison to applicable standards. Thus the EPA developed a sign test based on comparing the deterioration factors for the two fuels for each model group, where a higher deterioration factor for HiTEC 3000 is evidence of an adverse effect. In this section we describe more powerful parametric tests that compare deterioration factors for a given model. Our results also include weighted average tests which are analogous to those described previously.

Linear Regression

The deterioration factor is the fitted mean emissions at 50,000 miles divided by the fitted mean emissions at 4,000 miles. For the linear regression model, the deterioration factor for EEE is given by

$$DF(\text{EEE}) = \frac{\text{Intercept}(\text{EEE}) + 50000 \text{ Slope}(\text{EEE})}{\text{Intercept}(\text{EEE}) + 4000 \text{ Slope}(\text{EEE})} \quad (35)$$

using Equations 21 and 22 (for a given model, fuel, and pollutant). Since this statistic is the ratio of two normally distributed and dependent variables, the exact variance is not available in closed form. However, the variance can be estimated using the well-known delta method. Let Slope (EEE, true) and Intercept (EEE, true) denote the true unknown slope and intercept of the true regression line (rather than the regression line estimated from the data) and let DF (EEE, true) denote the true deterioration factor. Then, using the delta method, DF (EEE) is approximately given by

$$\begin{aligned} DF(EEE) = & DF(EEE, \text{true}) \\ & + [\text{Slope}(EEE) - \text{Slope}(EEE, \text{true})] \times \frac{\partial DF}{\partial \text{Slope}} \\ & + [\text{Intercept}(EEE) - \text{Intercept}(EEE, \text{true})] \times \frac{\partial DF}{\partial \text{Intercept}} \end{aligned} \quad (36)$$

where the partial derivative terms $\frac{\partial DF}{\partial \text{Slope}}$ and $\frac{\partial DF}{\partial \text{Intercept}}$ are given by

$$\frac{\partial DF}{\partial \text{Slope}} = \frac{46000 \text{ Intercept}(EEE)}{[\text{Intercept}(EEE) + 4000 \text{ Slope}(EEE)]^2} \quad (37)$$

and

$$\frac{\partial DF}{\partial \text{Intercept}} = \frac{-46000 \text{ Slope}(EEE)}{[\text{Intercept}(EEE) + 4000 \text{ Slope}(EEE)]^2} \quad (38)$$

Using this approximation, the variance of the estimated deterioration factor is given by the formula

$$\begin{aligned} & \text{Variance (slope EEE)} \times \left(\frac{\partial DF}{\partial \text{Slope}} \right)^2 + \text{Variance (Intercept EEE)} \times \left(\frac{\partial DF}{\partial \text{Intercept}} \right)^2 \\ & + 2 \text{ Covariance (slope EEE, intercept EEE)} \frac{\partial DF}{\partial \text{Slope}} \frac{\partial DF}{\partial \text{Intercept}} \end{aligned} \quad (39)$$

where the variances and covariance terms are given by Equations 25 to 27. Equation 39 is then evaluated by applying Equations 37 and 38 with estimated slopes replacing the true slopes. For each model the t test of the difference in deterioration factors is based on the observed difference divided by the square root of the variance of the difference; the variance of the difference is the sum of the variances for the two fuel deterioration factors.

Quadratic Regression

We consider the deterioration factor test based on quadratic regression for the 50,000 mile data. The similar test for the 75,000 mile data is based on the ratio of the fitted 75,000 mile emissions to the fitted 4,000 mile emissions; the procedure in that case is analogous. In this description we shall use the same notation as in our description of the quadratic regression slopes tests.

The deterioration factor for quadratic regression is given by

$$DF = \frac{a + 50000b + 50000^2c}{a + 4000b + 4000^2c} \quad (40)$$

In this case the delta method is based on the approximation

$$\hat{DF} = DF + (\hat{a} - a) \frac{\partial DF}{\partial a} + (\hat{b} - b) \frac{\partial DF}{\partial b} + (\hat{c} - c) \frac{\partial DF}{\partial c}, \quad (41)$$

where the hats denote estimated values, and the parameters without hats denote unknown true values. The partial derivatives are given by

$$\frac{\partial DF}{\partial a} = \frac{-46000 (b + 54000 c)}{(a + 4000b + 4000^2 c)^2} \quad (42)$$

$$\frac{\partial DF}{\partial b} = \frac{46000 [a - (50000)(4000)c]}{(a + 4000b + 4000^2 c)^2} \quad (43)$$

and

$$\frac{\partial DF}{\partial c} = \frac{46000 [54000a + (50000)(4000)b]}{(a + 4000b + 4000^2 c)^2} \quad (44)$$

and the variance of the deterioration factor (for a particular model, fuel, and pollutant) is approximately given by

$$\begin{aligned} \text{Var}(DF) = & \frac{\partial DF}{\partial a}^2 \text{Var}(a) + \frac{\partial DF}{\partial b}^2 \text{Var}(b) + \frac{\partial DF}{\partial c}^2 \text{Var}(c) \\ & + 2 \frac{\partial DF}{\partial a} \frac{\partial DF}{\partial b} \text{Cov}(a, b) + 2 \frac{\partial DF}{\partial a} \frac{\partial DF}{\partial c} \text{Cov}(a, c) \\ & + 2 \frac{\partial DF}{\partial b} \frac{\partial DF}{\partial c} \text{Cov}(b, c) \end{aligned} \quad (45)$$

The t test of the difference in deterioration factors is computed using Equations 40 and 45 (substituting the values in Equations 42 to 44) in a manner similar to the linear regression case.

Violation Mileage Test

The violation mileage is intended to estimate the first mileage at which the emissions exceed the standard. The estimate is based on the regression model. The corresponding statistical test, which regards the fuel effect as adverse if the violation mileage is earlier, is described in this section.

For each model the violation mileage is in most cases the first positive mileage at which the regression line (linear regression) or regression curve (quadratic regression) meets the Federal emissions standard for the given pollutant. If, however, the zero mile emissions estimated from the regression model exceeds the standard, then the violation mileage is 0 miles. If the first exceedance mileage is after 50,000 miles (or after 75,000 miles for the 75,000 mile data analysis), or if the regression line or curve lies below the standard for all positive mileages, then the violation mileage is defined by EPA as 99,000 miles to denote no violation during the lifespan of the vehicular model. The violation mileages for each fuel on a given model are compared; the fuel effect is adverse for that model if the violation mileage for HiTEC 3000 is less than the violation mileage for EEE. Deleting models with equal violation mileages, a simple sign test is carried out based on the number of models that have an adverse fuel effect.

For the linear model the first exceedance mileage in cases where the intercept does not exceed the standard (in such cases the violation mileage is 0 miles) is given by

$$(\text{standard} - \text{intercept})/\text{slope} \quad (46)$$

unless the slope is negative (in which case the violation mileage is 99,000 miles).

For the quadratic model, using the above notation in our description of the quadratic regression slope test, the violation mileage is 0 miles if a exceeds the standard. Suppose the estimated intercept a does not exceed the standard. Then the first exceedance mileage is the smallest positive root, if any, of the quadratic equation $a + bm + cm^2 = \text{std}$. If c equals zero then the violation mileage is found as in the linear regression model. If c is negative and b is not positive, then the regression curve lies below the standard for all positive mileages and the violation mileage is 99,000. If c is negative, b is positive, and the determinant $b^2 - 4c(a - \text{std})$ is negative, then the curve never exceeds the standard and the violation mileage is also 99,000. Otherwise, the first exceedance mileage is

$$\frac{-b + \sqrt{b^2 - 4c(a - \text{standard})}}{2c} \quad (47)$$

The violation mileage is the first exceedance mileage (Equation 47) or is 99,000 depending upon whether or not the first exceedance mileage is less than 50,000 miles.

Because the violation mileage is not a continuous function of the data, it is not practicable to get a good estimate of its variance. Thus a more powerful version of this test was not developed.

Maximum Percentage of Vehicles Failing Standard Test

The idea of the statistical test described in this section is to compare the failure rates for the two fuels, interpreting failure as exceedance of the standard. The failure rates are estimated using the regression models. Since the failure rate varies with mileage, the maximum estimated failure rate over the mileage accumulation interval is used for the comparison.

More precisely, the regression model (linear or quadratic) is used as described below to give an estimate of the percentage failures (vehicles with emissions above the

standard) at each mileage. The maximum over all mileages from zero to 50,000 miles is then computed (for the 75,000 mile data analysis substitute 75,000 for 50,000). This procedure is carried out for each model, fuel, and pollutant combination and the results for the eight models are compared using a sign test in a similar manner to the violation mileage test already discussed. HiTEC 3000 is assumed to have an adverse effect for a given model if the estimated maximum percentage for the HiTEC 3000 vehicles exceeds the estimated maximum percentage for the EEE vehicles.

Linear Regression

The linear regression model assumes that emissions at a given mileage m are given by

$$\text{Intercept} + m \times \text{Slope} + \text{error} \quad (48)$$

where the error is normally distributed with mean zero and variance σ^2 . Thus the probability that the emissions of a particular vehicle exceed the standard at mileage m is

$$\phi [(\text{Intercept} + m \times \text{Slope} - \text{std}) / \sigma] \quad (49)$$

where ϕ denotes the cumulative distribution function of the standard normal distribution. This follows easily from the assumed normality of the errors. The estimated percentage failures are found by multiplying Equation 49 by 100 to give the equation

$$100 * \phi [(\text{Intercept} + m \times \text{Slope} - \text{std}) / \sigma] \quad (50)$$

Suppose that the slope is positive. Since the term inside the parentheses of Equation 49 is strictly increasing with mileage, the maximum estimated percentage failures over the first 50,000 miles occurs at 50,000 miles. Similarly, if the slope is negative, then the maximum occurs at 0 miles. The maximum estimated percentage failures is found from Equation 50, substituting the values from Equations 21 and 22 for the slope and intercept, Equation 29 for the variance σ^2 , and either 0 or 50,000 for the

mileage, according to the sign of the slope. The maximum likelihood estimate in Equation 29 is used instead to estimate σ^2 rather than Equation 28 so that the estimate of the maximum percentage failures has the desirable statistical properties of a maximum likelihood estimator.

Quadratic Regression

In a similar manner to the linear regression case, the estimated percentage failures at mileage m is given by the equation

$$100 \times \Phi [(a + bm + cm^2 - \text{std})/\sigma] \quad (51)$$

using the previous notation.

The maximum of the quadratic expression inside the parentheses of Equation 51 occurs at $-b/2c$ provided that c is negative and this mileage lies between 0 and 50,000. Otherwise the maximum over that interval occurs at one of the endpoints and can be simply obtained by comparing the values of the expression at the endpoint mileages 0 and 50,000. The estimated maximum percentage failures is computed by substituting into Equation 51 the quadratic regression estimates for a , b , and c , the variance estimate (Eq. 29) for σ^2 , and the mileage at which the maximum occurs for m .

Cause-or-Contribute Test

The intent of the final EPA test, called the cause-or-contribute test, is to determine if any adverse effects detected result in more failures of emissions standards for the waiver fuel than for clear fuel. In a similar manner to the maximum percentage of vehicles failing standard test, the percentage failures at each mileage for each fuel estimated from the regressions are compared and the fuel with a higher percentage at a given mileage is regarded as having an adverse effect. Failure rates lower than 10 percent are regarded as having no practical importance, for the purpose of applying this test.

The calculation is based on Equations 50 or 51 in the previous section, depending on whether linear or quadratic regression is used. For each mileage m in the mileage accumulation interval (either 0 to 50,000 miles or 0 to 75,000 miles) these formulae give the estimated percentage failures at that mileage for a given vehicular model, fuel and pollutant. For a fixed model and pollutant, the estimates for each fuel and at each mileage are compared to determine whether the estimated percentage failures for HiTEC 3000 exceed both 10 percent and the estimated percentage failures for EEE. (The numerical comparison was made at every multiple of 1,000 miles inside the mileage accumulation interval. For consistency we also made the numerical comparison at the two exact mileages at which the estimated maximum percentage failures, as calculated in the maximum percentage failing standard test, occurred; one for each fuel.) The effect is regarded as adverse for the given model in such a situation. The results are used in a sign test of the number of models with an "adverse" effect out of the eight models in the test fleet.

Attachment D

TABULATED RESULTS FOR ALL STATISTICAL
ANALYSES OF 50,000 MILE DATA

Attachment D
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Description	Version	Data Set	Page Number		
			HC	NO _x	CO
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	Unequal car means	ETHYL4S2	D-4	D-5	D-6
1K to 5K test	Equal car effects	ETHYL4S2	D-7	D-8	D-9
	Unequal car effects	ETHYL4S2	D-10	D-11	D-12
1K to 50K test	Equal car effects	ETHYL4S2	D-13	D-14	D-15
	Unequal car effects	ETHYL4S2	D-16	D-17	D-18
Integrated emissions test	1K - 50K	ETHYL4S2	D-19	D-20	D-21
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Mean effects (50,000 miles and 75,000 miles analyses)		ETHYL4S2	D-25	D-26	D-27
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		ETHYL4S3	D-31	D-32	D-33
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Linear regression slopes test		ETHYL4S2	D-37	D-38	D-39
Deterioration factors test	Linear regression	ETHYL4S2	D-40	D-41	D-42
Violation mileage test	Linear regression	ETHYL4S2	D-43	D-44	D-45
Maximum percentage of vehicles failing standard test	Linear regression	ETHYL4S2	D-46	D-47	D-48
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Quadratic coefficient test	Quadratic regression	ETHYL4S2	D-55	D-56	D-57
Deterioration factors test	Quadratic regression	ETHYL4S2	D-58	D-59	D-60
Violation mileage test	Quadratic regression	ETHYL4S2	D-61	D-62	D-63
Maximum percentage of vehicles failing standard test	Quadratic regression	ETHYL4S2	D-64	D-65	D-66
Cause or contribute test	Linear regression	ETHYL4S2	D-67	D-68	D-69
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Ethyl Corporation HiTEC 3000 Fleet Testing Program

Initial Emissions Test
(assuming equal car-means)Data Set ETHYL4S2
Pollutant Hydrocarbons

Model	Emissions at 1000 mi (g/mi)			----- Rank Sum Test -----			T-test
	EEE	(a) HT3	Sign	Test Statistic	Mean	Sig.Level (%)(b)	Sig.Level (%)(b)
D	0.285	0.279	-	15.5	12.0	61.00	40.15
E	0.099	0.104	+	21.0	18.0	70.00	68.38
F	0.168	0.167	-	20.0	18.0	81.80	95.63
T	0.189	0.207	+	7.0	18.0	9.40	13.33
C	0.123	0.129	+	14.5	18.0	58.80	41.94
G	0.101	0.100	-	20.5	18.0	81.80	91.65
H	0.182	0.168	-	26.0	18.0	24.00	15.41
I	0.173	0.162	-	22.5	18.0	58.80	43.62
Weighted Average(c)	0.162	0.159	-				57.30
Total				147.0	138.0	60.03	

EPA Sign Test: Observation of 3 '+' sign(s) in 8 trials rejects the hypothesis of no difference in initial emission levels between the fuels at the 72.66 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no difference in initial emission levels between the fuels is rejected at the 60.03 percent significance level(b).

Weighted Average Test: The hypothesis of no difference in initial emission levels between the fuels is rejected at the 57.30 percent significance level(b).

Notes:

- Each figure is the mean of the 1,000 mile emissions tests.
- The lower the significance level, the greater the evidence of a difference in initial emission levels between the fuels.
- The weights for the weighted averages are proportional to 1988 sales figures.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Initial Emissions Test
 (assuming equal car-means)
 Data Set ETHYL4S2
 Pollutant Nitrogen Oxides

Model	Emissions at 1000 mi (g/mi)			----- Rank Sum Test -----			T-test
	EEE	(a) HT3	Sign	Test Statistic	Mean	Sig.Level (%)(b)	Sig.Level (%)(b)
D	0.55	0.63	+	4.0	12.0	11.40	10.69
E	0.17	0.20	+	7.0	18.0	9.40	9.49
F	0.50	0.46	-	26.0	18.0	24.00	21.43
T	0.71	0.69	-	22.0	18.0	58.80	85.41
C	0.09	0.10	+	13.0	18.0	48.40	35.38
G	0.14	0.17	+	3.0	18.0	1.60	0.53
H	0.35	0.39	+	13.0	18.0	48.40	56.80
I	0.21	0.24	+	16.0	18.0	81.80	54.35
Weighted Average(c)	0.34	0.35	+				46.31
Total				104.0	138.0	4.78	

EPA Sign Test: Observation of 6 '+' sign(s) in 8 trials rejects the hypothesis of no difference in initial emission levels between the fuels at the 28.91 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no difference in initial emission levels between the fuels is rejected at the 4.78 percent significance level(b).

Weighted Average Test: The hypothesis of no difference in initial emission levels between the fuels is rejected at the 46.31 percent significance level(b).

Notes:

- Each figure is the mean of the 1,000 mile emissions tests.
- The lower the significance level, the greater the evidence of a difference in initial emission levels between the fuels.
- The weights for the weighted averages are proportional to 1988 sales figures.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Initial Emissions Test
(assuming equal car-means)
Data Set ETHYL4S2
Pollutant Carbon Monoxide

Model	Emissions at 1000 mi (g/mi)			----- Rank Sum Test -----			T-test Sig.Level (%)(b)
	EEE	(a) HT3	Sign	Test Statistic	Mean	Sig.Level (%)(b)	
D	1.69	1.72	+	13.0	12.0	91.40	80.96
E	2.14	2.42	+	12.0	18.0	39.40	41.49
F	0.55	0.58	+	16.0	18.0	81.80	76.18
T	1.61	1.83	+	9.0	18.0	18.00	15.04
C	1.24	1.38	+	7.0	18.0	9.40	11.70
G	0.76	0.79	+	12.0	18.0	39.40	57.25
H	1.43	1.30	-	31.0	18.0	4.20	6.04
I	1.61	1.54	-	19.0	18.0	93.80	71.00
Weighted Average(c)	1.38	1.41	+				51.74
Total				119.0	138.0	26.86	

EPA Sign Test: Observation of 6 '+' sign(s) in 8 trials rejects the hypothesis of no difference in initial emission levels between the fuels at the 28.91 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no difference in initial emission levels between the fuels is rejected at the 26.86 percent significance level(b).

Weighted Average Test: The hypothesis of no difference in initial emission levels between the fuels is rejected at the 51.74 percent significance level(b).

Notes:

- Each figure is the mean of the 1,000 mile emissions tests.
- The lower the significance level, the greater the evidence of a difference in initial emission levels between the fuels.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 16, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Initial Emissions Test
(not assuming equal car-means)
Data Set ETHYL4S2
Pollutant Hydrocarbons

Model	Emissions at 1000 mi.(g/mi)(a)		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
	EEE	HT3		
D	0.285	0.279	-	40.96
E	0.099	0.104	+	39.20
F	0.168	0.167	-	93.78
T	0.189	0.207	+	17.72
C	0.123	0.129	+	30.03
G	0.101	0.100	-	92.37
H	0.181	0.168	-	7.34
I	0.173	0.162	-	21.47
Weighted Average(c)	0.162	0.159	-	42.90

EPA Sign Test: Observation of 3 '+' sign(s) in 8 trials rejects the hypothesis of no difference in initial emission levels between the fuels at the 72.66 percent significance level(b).

Weighted Average Test: The hypothesis of no difference in initial emission levels between the fuels is rejected at the 42.90 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of a difference in initial emission levels between the fuels.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 18, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Initial Emissions Test
(not assuming equal car-means)
Data Set ETHYL4S2
Pollutant Nitrogen Oxides

Model	Emissions at 1000 mi.(g/mi)(a) EEE HT3		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
D	0.55	0.63	+	2.34
E	0.17	0.20	+	5.90
F	0.50	0.46	-	13.13
T	0.71	0.69	-	57.78
C	0.09	0.10	+	33.97
G	0.14	0.17	+	0.36
H	0.35	0.39	+	15.26
I	0.21	0.24	+	0.13
Weighted Average(c)	0.34	0.35	+	4.56

EPA Sign Test: Observation of 6 '+' sign(s) in 8 trials rejects the hypothesis of no difference in initial emission levels between the fuels at the 28.91 percent significance level(b).

Weighted Average Test: The hypothesis of no difference in initial emission levels between the fuels is rejected at the 4.56 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of a difference in initial emission levels between the fuels.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 18, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Initial Emissions Test
(not assuming equal car-means)
Data Set ETHYL4S2
Pollutant Carbon Monoxide

Model	Emissions at 1000 mi. (g/mi) (a)		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
	EEE	HT3		
D	1.69	1.72	+	83.98
E	2.14	2.42	+	6.85
F	0.55	0.58	+	64.32
T	1.61	1.83	+	19.15
C	1.24	1.38	+	6.29
G	0.76	0.79	+	6.93
H	1.43	1.30	-	5.89
I	1.61	1.54	-	55.15
Weighted Average(c)	1.38	1.41	+	31.64

EPA Sign Test: Observation of 6 '+' sign(s) in 8 trials rejects the hypothesis of no difference in initial emission levels between the fuels at the 28.91 percent significance level(b).

Weighted Average Test: The hypothesis of no difference in initial emission levels between the fuels is rejected at the 31.64 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of a difference in initial emission levels between the fuels.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 18, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Change in Emissions From 1,000 to 5,000 Miles
(assuming equal car effects)Data Set ETHYL4S2
Pollutant Hydrocarbons

Model	Change in Emissions (g/mi) from 1,000 to 5,000		mi(a) Sign	----- Test Statistic	Rank Mean	Sum Test Sig.Level (%)(b)	T-test Sig.Level (%)(b)
	EEE	HT3					
D	0.012	0.040	+	1.0	3.0	20.00	7.93
E	0.031	0.057	+	2.0	4.5	20.00	10.05
F	0.078	0.086	+	3.0	4.5	35.00	25.27
T	0.042	0.050	+	3.0	4.5	35.00	28.53
C	0.020	0.031	+	3.0	4.5	35.00	32.92
G	0.012	0.017	+	4.0	4.5	50.00	34.60
H	0.008	0.039	+	0.0	4.5	5.00	6.04
I	-0.003	0.012	+	4.0	4.5	50.00	30.05
Weighted Average(c)	0.024	0.041	+				0.53
Total				20.0	34.5	1.07	

EPA Sign Test: Observation of 8 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 0.39 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 1.07 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 0.53 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 5,000 miles minus the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect
- The weights for the weighted averages are proportional to 1988 sales figures.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Change in Emissions From 1,000 to 5,000 Miles
(assuming equal car effects)Data Set ETHYL4S2
Pollutant Nitrogen Oxides

Model	Change in Emissions (g/mi) from 1,000 to 5,000 mi(a) EEE HT3 Sign			----- Rank Sum Test ----- Test Mean Sig.Level Statistic (%) (b)	T-test Sig.Level (%) (b)
D	0.01	-0.06	-	6.0 3.0 100.00	93.51
E	0.10	0.01	-	9.0 4.5 100.00	99.50
F	0.13	0.17	+	3.0 4.5 35.00	18.65
T	0.09	-0.16	-	8.0 4.5 95.00	93.33
C	0.14	0.11	-	8.0 4.5 95.00	91.48
G	0.09	0.09	-	5.0 4.5 65.00	58.40
H	-0.01	0.12	+	3.0 4.5 35.00	19.35
I	0.16	0.04	-	8.0 4.5 95.00	90.93
Weighted Average(c)	0.09	0.06	-		78.31
Total				50.0 34.5 99.30	

EPA Sign Test: Observation of 2 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 96.48 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 99.30 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 78.31 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 5,000 miles minus the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 18, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Change in Emissions From 1,000 to 5,000 Miles
(assuming equal car effects)

Data Set ETHYL4S2

Pollutant Carbon Monoxide

Model	Change in Emissions (g/mi) from 1,000 to 5,000 mi(a) EEE HT3 Sign			----- Rank Sum Test ----- Test Mean Sig.Level Statistic (%) (b)	T-test Sig.Level (%) (b)
D	0.08	0.04	-	4.0 3.0 80.00	67.38
E	0.51	1.07	+	2.0 4.5 20.00	17.74
F	0.32	0.14	-	8.0 4.5 95.00	94.45
T	0.66	0.83	+	1.0 4.5 10.00	3.79
C	0.22	0.30	+	4.0 4.5 50.00	34.91
G	0.48	0.34	-	9.0 4.5 100.00	96.80
H	0.20	0.25	+	3.0 4.5 35.00	39.51
I	0.22	0.20	-	5.0 4.5 65.00	52.27
Weighted Average(c)	0.33	0.39	+		26.41
Total				36.0 34.5 59.40	

EPA Sign Test: Observation of 4 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 63.67 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 59.40 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 26.41 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 5,000 miles minus the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect
- The weights for the weighted averages are proportional to 1988 sales figures.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Change in Emissions from 1,000 to 5,000 Miles
(not assuming equal car effects)

Data Set ETHYL4S2
Pollutant Hydrocarbons

Model	Change in Emissions from 1,000 to 5,000 mi (g/mi)(a)		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
	EEE	HT3		
D	0.012	0.040	+	1.43
E	0.031	0.057	+	3.92
F	0.078	0.086	+	25.12
T	0.042	0.050	+	35.67
C	0.020	0.031	+	12.96
G	0.012	0.017	+	36.78
H	0.008	0.039	+	0.70
I	-0.003	0.012	+	7.66
Weighted Average(c)	0.024	0.041	+	0.02

EPA Sign Test: Observation of 8 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 0.39 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 0.02 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 5,000 miles minus the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 18, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Change in Emissions from 1,000 to 5,000 Miles
(not assuming equal car effects)

Data Set ETHYL4S2

Pollutant Nitrogen Oxides

Model	Change in Emissions from 1,000 to 5,000 mi (g/mi)(a)		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
	EEE	HT3		
D	0.01	-0.06	-	97.55
E	0.10	0.01	-	99.99
F	0.13	0.17	+	11.57
T	0.09	-0.16	-	100.00
C	0.14	0.11	-	89.18
G	0.09	0.09	-	61.55
H	-0.01	0.12	+	0.05
I	0.16	0.04	-	100.00
Weighted Average(c)	0.09	0.06	-	99.67

EPA Sign Test: Observation of 2 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 96.48 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 99.67 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 5,000 miles minus the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 18, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Change in Emissions from 1,000 to 5,000 Miles
(not assuming equal car effects)Data Set ETHYL4S2
Pollutant Carbon Monoxide

Model	Change in Emissions from 1,000 to 5,000 mi (g/mi)(a)		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
	EEE	HT3		
D	0.08	0.04	-	61.93
E	0.51	1.07	+	4.22
F	0.32	0.14	-	99.26
T	0.66	0.83	+	21.49
C	0.22	0.30	+	28.81
G	0.48	0.34	-	99.22
H	0.20	0.25	+	29.06
I	0.22	0.20	-	55.40
Weighted Average(c)	0.33	0.39	+	14.53

EPA Sign Test: Observation of 4 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 63.67 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 14.53 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 5,000 miles minus the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 18, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Change in Emissions From 1,000 to 50,000 Miles
(assuming equal car effects)Data Set ETHYL4S2
Pollutant Hydrocarbons

Model	Change in Emissions (g/mi) from 1,000 to 50,000 mi(a) EEE HT3 Sign			----- Rank Test Statistic	Sum Test Mean	----- Sig.Level (%)(b)	T-test Sig.Level (%)(b)
D	0.320	0.442	+	2.0	3.0	40.00	17.09
E	0.113	0.090	-	7.0	4.5	90.00	78.55
F	0.561	0.525	-	6.0	4.5	80.00	72.81
T	0.257	0.247	-	6.0	4.5	80.00	60.46
C	0.060	0.091	+	2.0	4.5	20.00	13.41
G	0.022	0.053	+	1.0	4.5	10.00	10.49
H	0.163	0.168	+	4.0	4.5	50.00	43.29
I	0.021	0.033	+	4.0	4.5	50.00	38.46
Weighted Average(c)	0.182	0.187	+				35.50
Total				32.0	34.5	34.59	

EPA Sign Test: Observation of 5 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 36.33 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 34.59 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 35.50 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 50,000 miles minus the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 20, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Change in Emissions From 1,000 to 50,000 Miles

(assuming equal car effects)

Data Set ETHYL4S2

Pollutant Nitrogen Oxides

Model	Change in Emissions (g/mi) from 1,000 to 50,000 mi(a)			----- Rank Test Statistic	Sum Test Mean	----- Sig.Level (%)(b)	T-test Sig.Level (%)(b)
	EEE	HT3	Sign				
D	-0.17	-0.15	+	2.0	3.0	40.00	36.27
E	0.23	0.19	-	6.0	4.5	80.00	77.17
F	0.65	0.31	-	7.0	4.5	90.00	87.24
T	0.07	-0.06	-	7.0	4.5	90.00	85.41
C	0.38	0.21	-	8.0	4.5	95.00	88.92
G	0.23	0.18	-	7.0	4.5	90.00	86.35
H	0.10	-0.04	-	7.0	4.5	90.00	85.28
I	0.25	0.15	-	7.0	4.5	90.00	81.64
Weighted Average(c)	0.24	0.10	-				99.71
Total				51.0	34.5	99.56	

EPA Sign Test: Observation of 1 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 99.61 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 99.56 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 99.71 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 50,000 miles minus the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 20, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Change in Emissions From 1,000 to 50,000 Miles
(assuming equal car effects)

Data Set ETHYL4S2

Pollutant Carbon Monoxide

Model	Change in Emissions (g/mi) from 1,000 to 50,000 mi(a)			----- Rank Test Statistic	Sum Test Mean	----- Sig.Level (%)(b)	T-test Sig.Level (%)(b)
	EEE	HT3	Sign				
D	3.52	3.71	+	2.0	3.0	40.00	21.14
E	4.28	3.21	-	9.0	4.5	100.00	94.76
F	1.99	1.10	-	9.0	4.5	100.00	99.57
T	4.55	3.78	-	7.0	4.5	90.00	78.60
C	1.21	1.52	+	4.0	4.5	50.00	22.86
G	1.52	1.08	-	6.0	4.5	80.00	77.84
H	3.08	2.64	-	8.0	4.5	95.00	94.59
I	1.02	1.00	-	5.0	4.5	65.00	54.80
Weighted Average(c)	2.57	2.15	-				99.82
Total				50.0	34.5	99.30	

EPA Sign Test: Observation of 2 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 96.48 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 99.30 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 99.82 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 50,000 miles minus the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 20, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Change in Emissions from 1,000 to 50,000 Miles
(not assuming equal car effects)

Data Set ETHYL4S2
Pollutant Hydrocarbons

Model	Change in Emissions from 1,000 to 50,000 mi (g/mi)(a)		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
	EEE	HT3		
D	0.320	0.442	+	0.02
E	0.113	0.090	-	94.31
F	0.561	0.525	-	75.92
T	0.257	0.247	-	67.65
C	0.060	0.091	+	3.63
G	0.022	0.053	+	0.90
H	0.163	0.168	+	37.21
I	0.021	0.033	+	28.50
Weighted Average(c)	0.182	0.187	+	28.85

EPA Sign Test: Observation of 5 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 36.33 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 28.85 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 50,000 miles minus the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 20, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Change in Emissions from 1,000 to 50,000 Miles
(not assuming equal car effects)

Data Set ETHYL4S2

Pollutant Nitrogen Oxides

Model	Change in Emissions from 1,000 to 50,000 mi (g/mi)(a)		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
	EEE	HT3		
D	-0.17	-0.15	+	26.22
E	0.23	0.19	-	93.26
F	0.65	0.31	-	100.00
T	0.07	-0.06	-	99.27
C	0.38	0.21	-	100.00
G	0.23	0.18	-	99.99
H	0.10	-0.04	-	99.88
I	0.25	0.15	-	99.91
Weighted Average(c)	0.24	0.10	-	100.00

EPA Sign Test: Observation of 1 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 99.61 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 100.00 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 50,000 miles minus the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 20, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Change in Emissions from 1,000 to 50,000 Miles
(not assuming equal car effects)

Data Set ETHYL4S2

Pollutant Carbon Monoxide

Model	Change in Emissions from 1,000 to 50,000 mi (g/mi)(a)		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
	EEE	HT3		
D	3.52	3.71	+	24.48
E	4.28	3.21	-	99.83
F	1.99	1.10	-	100.00
T	4.55	3.78	-	96.14
C	1.21	1.52	+	18.29
G	1.52	1.08	-	99.61
H	3.08	2.64	-	90.23
I	1.02	1.00	-	53.42
Weighted Average(c)	2.57	2.15	-	99.99

EPA Sign Test: Observation of 2 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 96.48 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected at the 99.99 percent significance level(b).

Notes:

- Each figure is the mean of the car-means at 50,000 miles minus the mean of the car-means at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 20, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Integrated Emissions Test
Data Set ETHYL4S2
Pollutant Hydrocarbons

Model	Emissions Rate Increase (g/mi) from 1,000 to 50,000 mi(a) EEE HT3 Sign			----- Rank Sum Test ----- Test Mean Sig.Level Statistic (%) (b)	T-test Sig.Level (%) (b)
D	0.187	0.243	+	0.0 3.0 10.00	4.59
E	0.068	0.085	+	2.0 4.5 20.00	19.18
F	0.308	0.306	-	5.0 4.5 65.00	54.90
T	0.124	0.144	+	3.0 4.5 35.00	18.03
C	0.051	0.086	+	0.0 4.5 5.00	1.51
G	0.028	0.058	+	0.0 4.5 5.00	1.91
H	0.089	0.098	+	4.0 4.5 50.00	29.39
I	0.011	0.030	+	3.0 4.5 35.00	17.90
Weighted Average(c)	0.102	0.119	+		0.30
Total				17.0 34.5 0.28	

EPA Sign Test: Observation of 7 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 3.52 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no adverse HiTEC 3000 effect is rejected 0.28 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected 0.30 percent significance level(b).

Notes:

- Each figure is the mean of the emissions rate increases for each car. The emissions rate increase is the estimated total emissions (in g) from 1,000 to 50,000 miles, divided by the accumulated mileage, minus the initial emissions rate at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Integrated Emissions Test
Data Set ETHYL4S2
Pollutant Nitrogen Oxides

Model	Emissions Rate Increase (g/mi) from 1,000 to 50,000 mi(a) EEE HT3 Sign			----- Rank Sum Test ----- Test Mean Sig.Level Statistic (%) (b)	T-test Sig.Level (%) (b)
D	-0.11	-0.14	-	3.0 3.0 60.00	69.63
E	0.19	0.14	-	8.0 4.5 95.00	93.86
F	0.34	0.21	-	9.0 4.5 100.00	100.00
T	0.06	-0.16	-	9.0 4.5 100.00	94.25
C	0.26	0.17	-	9.0 4.5 100.00	97.30
G	0.22	0.18	-	9.0 4.5 100.00	92.91
H	0.04	0.05	+	5.0 4.5 65.00	45.91
I	0.19	0.13	-	7.0 4.5 90.00	85.47
Weighted Average(c)	0.16	0.08	-		98.56
Total				59.0 34.5 99.99	

EPA Sign Test: Observation of 1 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 99.61 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no adverse HiTEC 3000 effect is rejected 99.99 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected 98.56 percent significance level(b).

Notes:

- Each figure is the mean of the emissions rate increases for each car. The emissions rate increase is the estimated total emissions (in g) from 1,000 to 50,000 miles, divided by the accumulated mileage, minus the initial emissions rate at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 20, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Integrated Emissions Test
Data Set ETHYL4S2
Pollutant Carbon Monoxide

Model	Emissions Rate Increase (g/mi) from 1,000 to 50,000 mi(a) EEE HT3 Sign			----- Rank Sum Test ----- Test Mean Sig.Level Statistic (%) (b)	T-test Sig.Level (%) (b)
D	1.84	1.83	-	4.0 3.0 80.00	51.74
E	2.24	2.43	+	3.0 4.5 35.00	36.10
F	0.99	0.48	-	9.0 4.5 100.00	99.48
T	2.07	2.00	-	6.0 4.5 80.00	66.48
C	1.23	1.27	+	2.0 4.5 20.00	42.15
G	1.05	1.02	-	6.0 4.5 80.00	71.84
H	1.80	1.63	-	6.0 4.5 80.00	78.43
I	0.73	0.77	+	3.0 4.5 35.00	42.66
Weighted Average(c)	1.47	1.37	-		86.17
Total				39.0 34.5 76.23	

EPA Sign Test: Observation of 3 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 85.55 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no adverse HiTEC 3000 effect is rejected 76.23 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected 86.17 percent significance level(b).

Notes:

- Each figure is the mean of the emissions rate increases for each car. The emissions rate increase is the estimated total emissions (in g) from 1,000 to 50,000 miles, divided by the accumulated mileage, minus the initial emissions rate at 1,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 20, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Integrated Emissions Test
Data Set ETHYL4S2
Pollutant Hydrocarbons

Model	Emissions Rate Increase (g/mi) from 5,000 to 50,000 mi(a) EEE HT3 Sign			----- Rank Sum Test ----- Test Mean Sig.Level Statistic (%) (b)	T-test Sig.Level (%) (b)
D	0.190	0.223	+	1.0 3.0 20.00	12.34
E	0.042	0.033	-	5.0 4.5 65.00	70.55
F	0.253	0.243	-	6.0 4.5 80.00	69.03
T	0.092	0.105	+	3.0 4.5 35.00	17.86
C	0.034	0.062	+	1.0 4.5 10.00	10.68
G	0.018	0.046	+	0.0 4.5 5.00	0.79
H	0.089	0.066	-	6.0 4.5 80.00	78.48
I	0.016	0.020	+	4.0 4.5 50.00	37.63
Weighted Average(c)	0.086	0.087	+		44.86
Total				26.0 34.5 8.88	

EPA Sign Test: Observation of 5 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 36.33 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no adverse HiTEC 3000 effect is rejected 8.88 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected 44.86 percent significance level(b).

Notes:

- Each figure is the mean of the emissions rate increases for each car. The emissions rate increase is the estimated total emissions (in g) from 5,000 to 50,000 miles, divided by the accumulated mileage, minus the initial emissions rate at 5,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 21, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Integrated Emissions Test
Data Set ETHYL4S2
Pollutant Nitrogen Oxides

Model	Emissions Rate Increase (g/mi) from 5,000 to 50,000 mi(a) EEE HT3 Sign			----- Rank Sum Test ----- Test Mean Sig.Level Statistic (%) (b)	T-test Sig.Level (%) (b)
D	-0.13	-0.09	+	0.0 3.0 10.00	11.62
E	0.10	0.14	+	3.0 4.5 35.00	16.53
F	0.24	0.05	-	9.0 4.5 100.00	99.02
T	-0.03	-0.00	+	4.0 4.5 50.00	41.15
C	0.13	0.06	-	7.0 4.5 90.00	91.45
G	0.14	0.10	-	9.0 4.5 100.00	99.37
H	0.05	-0.07	-	9.0 4.5 100.00	99.08
I	0.05	0.11	+	3.0 4.5 35.00	18.33
Weighted Average(c)	0.08	0.03	-		98.47
Total				44.0 34.5 93.41	

EPA Sign Test: Observation of 4 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 63.67 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no adverse HiTEC 3000 effect is rejected 93.41 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected 98.47 percent significance level(b).

Notes:

- Each figure is the mean of the emissions rate increases for each car. The emissions rate increase is the estimated total emissions (in g) from 5,000 to 50,000 miles, divided by the accumulated mileage, minus the initial emissions rate at 5,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 21, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Integrated Emissions Test
Data Set ETHYL4S2
Pollutant Carbon Monoxide

Model	Emissions Rate Increase (g/mi) from 5,000 to 50,000 mi(a) EEE HT3 Sign			----- Test Test Statistic	Rank Sum Mean	----- Test Sig.Level (%)(b)	T-test Sig.Level (%)(b)
D	1.91	1.95	+	4.0	3.0	80.00	43.52
E	1.90	1.53	-	8.0	4.5	95.00	93.56
F	0.75	0.38	-	9.0	4.5	100.00	99.22
T	1.57	1.31	-	7.0	4.5	90.00	91.25
C	1.11	1.06	-	3.0	4.5	35.00	61.01
G	0.64	0.75	+	0.0	4.5	5.00	2.06
H	1.75	1.52	-	9.0	4.5	100.00	88.62
I	0.57	0.63	+	4.0	4.5	50.00	33.67
Weighted Average(c)	1.25	1.09	-				99.69
Total				44.0	34.5	93.41	

EPA Sign Test: Observation of 3 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 85.55 percent significance level(b).

EPA Overall Rank Sum Test: The hypothesis of no adverse HiTEC 3000 effect is rejected 93.41 percent significance level(b).

Weighted Average Test: The hypothesis of no adverse HiTEC 3000 effect is rejected 99.69 percent significance level(b).

Notes:

- Each figure is the mean of the emissions rate increases for each car. The emissions rate increase is the estimated total emissions (in g) from 5,000 to 50,000 miles, divided by the accumulated mileage, minus the initial emissions rate at 5,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
March 21, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Mean Effects of HiTEC 3000

Data Set: ETHYL4S2

Pollutant: Hydrocarbons

OBSERVED INTEGRATED EMISSIONS PER MILE

<u>Beginning Mileage</u>	<u>Ending Mileage</u>	<u>Scaling</u>	<u>Mean Integrated Emissions (a)</u>		<u>HiTEC 3000 Effect (b) (g/mi)</u>
			<u>HiTEC 3000 (g/mi)</u>	<u>EEE (g/mi)</u>	
1,000	50,000	Unscaled	0.279	0.263	0.015
1,000	50,000	Scaled (c)	0.281	0.263	0.018
50,000	75,000	Unscaled	0.357	0.340	0.017
50,000	75,000	Scaled (c)	0.360	0.340	0.019
1,000	75,000	Unscaled	0.305	0.289	0.016
1,000	75,000	Scaled (c)	0.307	0.289	0.018

OBSERVED MEAN EMISSIONS

<u>Mileage</u>	<u>Scaling</u>	<u>Weighted Average Emissions (d)</u>		<u>HiTEC 3000 Effect (b) (g/mi)</u>
		<u>HiTEC 3000 (g/mi)</u>	<u>EEE (g/mi)</u>	
25,000	Unscaled	0.274	0.272	0.002
25,000	Scaled (c)	0.277	0.272	0.005
50,000	Unscaled	0.346	0.344	0.003
50,000	Scaled (c)	0.349	0.344	0.005
75,000	Unscaled	0.357	0.329	0.028
75,000	Scaled (c)	0.360	0.329	0.031
1,000	Unscaled	0.159	0.162	-0.002

Notes

- (a) For each car, the emissions are integrated from the beginning mileage to the ending mileage and expressed as a rate in g/mi. Each figure is the mean of the car rates, weighting models by 1988 sales.
- (b) These numbers give the average difference in emissions (HiTEC 3000 minus EEE).
- (c) The HiTEC 3000 emissions are rescaled by subtraction of the initial difference between HiTEC 3000 and EEE, given in the final row of the table.
- (d) Each figure is the mean of the car-means at the given mileage.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Mean Effects of HiTEC 3000

Data Set: ETHYL4S2

Pollutant: Nitrogen Oxides

OBSERVED INTEGRATED EMISSIONS PER MILE

<u>Beginning Mileage</u>	<u>Ending Mileage</u>	<u>Scaling</u>	<u>Mean Integrated Emissions (a)</u>		<u>HiTEC 3000 Effect (b) (g/mi)</u>
			<u>HiTEC 3000 (g/mi)</u>	<u>EEE (g/mi)</u>	
1,000	50,000	Unscaled	0.44	0.49	-0.05
1,000	50,000	Scaled (c)	0.42	0.49	-0.07
50,000	75,000	Unscaled	0.48	0.67	-0.19
50,000	75,000	Scaled (c)	0.46	0.67	-0.21
1,000	75,000	Unscaled	0.45	0.55	-0.10
1,000	75,000	Scaled (c)	0.43	0.55	-0.11

OBSERVED MEAN EMISSIONS

<u>Mileage</u>	<u>Scaling</u>	<u>Weighted Average Emissions (d)</u>		<u>HiTEC 3000 Effect (b) (g/mi)</u>
		<u>HiTEC 3000 (g/mi)</u>	<u>EEE (g/mi)</u>	
25,000	Unscaled	0.48	0.52	-0.04
25,000	Scaled (c)	0.47	0.52	-0.05
50,000	Unscaled	0.45	0.58	-0.12
50,000	Scaled (c)	0.44	0.58	-0.14
75,000	Unscaled	0.47	0.72	-0.25
75,000	Scaled (c)	0.46	0.72	-0.27
1,000	Unscaled	0.35	0.34	0.02

Notes

- (a) For each car, the emissions are integrated from the beginning mileage to the ending mileage and expressed as a rate in g/mi. Each figure is the mean of the car rates, weighting models by 1988 sales.
- (b) These numbers give the average difference in emissions (HiTEC 3000 minus EEE).
- (c) The HiTEC 3000 emissions are rescaled by subtraction of the initial difference between HiTEC 3000 and EEE, given in the final row of the table.
- (d) Each figure is the mean of the car-means at the given mileage.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Mean Effects of HiTEC 3000

Data Set: ETHYL4S2

Pollutant: Carbon Monoxide

OBSERVED INTEGRATED EMISSIONS PER MILE

<u>Beginning Mileage</u>	<u>Ending Mileage</u>	<u>Scaling</u>	<u>Mean Integrated Emissions (a)</u>		<u>HiTEC 3000 Effect (b) (g/mi)</u>
			<u>HiTEC 3000 (g/mi)</u>	<u>EEE (g/mi)</u>	
1,000	50,000	Unscaled	2.78	2.84	-0.06
1,000	50,000	Scaled (c)	2.75	2.84	-0.09
50,000	75,000	Unscaled	3.76	4.20	-0.44
50,000	75,000	Scaled (c)	3.72	4.20	-0.47
1,000	75,000	Unscaled	3.11	3.30	-0.18
1,000	75,000	Scaled (c)	3.08	3.30	-0.22

OBSERVED MEAN EMISSIONS

<u>Mileage</u>	<u>Scaling</u>	<u>Weighted Average Emissions (d)</u>		<u>HiTEC 3000 Effect (b) (g/mi)</u>
		<u>HiTEC 3000 (g/mi)</u>	<u>EEE (g/mi)</u>	
25,000	Unscaled	2.83	3.03	-0.20
25,000	Scaled (c)	2.79	3.03	-0.23
50,000	Unscaled	3.55	3.95	-0.40
50,000	Scaled (c)	3.52	3.95	-0.43
75,000	Unscaled	3.54	3.86	-0.33
75,000	Scaled (c)	3.50	3.86	-0.36
1,000	Unscaled	1.41	1.38	0.03

Notes

- (a) For each car, the emissions are integrated from the beginning mileage to the ending mileage and expressed as a rate in g/mi. Each figure is the mean of the car rates, weighting models by 1988 sales.
- (b) These numbers give the average difference in emissions (HiTEC 3000 minus EEE).
- (c) The HiTEC 3000 emissions are rescaled by subtraction of the initial difference between HiTEC 3000 and EEE, given in the final row of the table.
- (d) Each figure is the mean of the car-means at the given mileage.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Mean Effects of HiTEC 3000

Data Set: ETHYL4S

Pollutant: Hydrocarbons

OBSERVED INTEGRATED EMISSIONS PER MILE

Beginning Mileage	Ending Mileage	Scaling	Mean Integrated Emissions (a)		HiTEC 3000 Effect (b) (g/mi)
			HiTEC 3000 (g/mi)	EEE (g/mi)	
1,000	50,000	Unscaled	0.279	0.263	0.016
1,000	50,000	Scaled (c)	0.282	0.263	0.018
50,000	75,000	Unscaled	0.358	0.340	0.018
50,000	75,000	Scaled (c)	0.360	0.340	0.020
1,000	75,000	Unscaled	0.305	0.289	0.016
1,000	75,000	Scaled (c)	0.307	0.289	0.019

OBSERVED MEAN EMISSIONS

Mileage	Scaling	Weighted Average Emissions (d)		HiTEC 3000 Effect (b) (g/mi)
		HiTEC 3000 (g/mi)	EEE (g/mi)	
25,000	Unscaled	0.274	0.272	0.002
25,000	Scaled (c)	0.277	0.272	0.005
50,000	Unscaled	0.352	0.340	0.012
50,000	Scaled (c)	0.354	0.340	0.014
75,000	Unscaled	0.357	0.329	0.028
75,000	Scaled (c)	0.360	0.329	0.031
1,000	Unscaled	0.159	0.162	-0.002

Notes

- (a) For each car, the emissions are integrated from the beginning mileage to the ending mileage and expressed as a rate in g/mi. Each figure is the mean of the car rates, weighting models by 1988 sales.
- (b) These numbers give the average difference in emissions (HiTEC 3000 minus EEE).
- (c) The HiTEC 3000 emissions are rescaled by subtraction of the initial difference between HiTEC 3000 and EEE, given in the final row of the table.
- (d) Each figure is the mean of the car-means at the given mileage.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Mean Effects of HiTEC 3000

Data Set: ETHYL4S

Pollutant: Nitrogen Oxides

OBSERVED INTEGRATED EMISSIONS PER MILE

<u>Beginning Mileage</u>	<u>Ending Mileage</u>	<u>Scaling</u>	<u>Mean Integrated Emissions (a)</u>		<u>HiTEC 3000 Effect (b) (g/mi)</u>
			<u>HiTEC 3000 (g/mi)</u>	<u>EEE (g/mi)</u>	
1,000	50,000	Unscaled	0.44	0.49	-0.05
1,000	50,000	Scaled (c)	0.42	0.49	-0.07
50,000	75,000	Unscaled	0.48	0.67	-0.19
50,000	75,000	Scaled (c)	0.46	0.67	-0.21
1,000	75,000	Unscaled	0.45	0.55	-0.10
1,000	75,000	Scaled (c)	0.43	0.55	-0.11

OBSERVED MEAN EMISSIONS

<u>Mileage</u>	<u>Scaling</u>	<u>Weighted Average Emissions (d)</u>		<u>HiTEC 3000 Effect (b) (g/mi)</u>
		<u>HiTEC 3000 (g/mi)</u>	<u>EEE (g/mi)</u>	
25,000	Unscaled	0.48	0.52	-0.04
25,000	Scaled (c)	0.47	0.52	-0.05
50,000	Unscaled	0.46	0.58	-0.12
50,000	Scaled (c)	0.45	0.58	-0.13
75,000	Unscaled	0.47	0.72	-0.25
75,000	Scaled (c)	0.46	0.72	-0.27
1,000	Unscaled	0.35	0.34	0.02

Notes

- (a) For each car, the emissions are integrated from the beginning mileage to the ending mileage and expressed as a rate in g/mi. Each figure is the mean of the car rates, weighting models by 1988 sales.
- (b) These numbers give the average difference in emissions (HiTEC 3000 minus EEE).
- (c) The HiTEC 3000 emissions are rescaled by subtraction of the initial difference between HiTEC 3000 and EEE, given in the final row of the table.
- (d) Each figure is the mean of the car-means at the given mileage.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Mean Effects of HiTEC 3000

Data Set: ETHYL4S

Pollutant: Carbon Monoxide

OBSERVED INTEGRATED EMISSIONS PER MILE

Beginning Mileage	Ending Mileage	Scaling	Mean Integrated Emissions (a)		HiTEC 3000 Effect (b) (g/mi)
			HiTEC 3000 (g/mi)	EEE (g/mi)	
1,000	50,000	Unscaled	2.80	2.84	-0.05
1,000	50,000	Scaled (c)	2.76	2.84	-0.08
50,000	75,000	Unscaled	3.77	4.19	-0.42
50,000	75,000	Scaled (c)	3.74	4.19	-0.45
1,000	75,000	Unscaled	3.12	3.29	-0.17
1,000	75,000	Scaled (c)	3.09	3.29	-0.20

OBSERVED MEAN EMISSIONS

Mileage	Scaling	Weighted Average Emissions (d)		HiTEC 3000 Effect (b) (g/mi)
		HiTEC 3000 (g/mi)	EEE (g/mi)	
25,000	Unscaled	2.83	3.03	-0.20
25,000	Scaled (c)	2.79	3.03	-0.23
50,000	Unscaled	3.73	3.92	-0.19
50,000	Scaled (c)	3.70	3.92	-0.22
75,000	Unscaled	3.54	3.86	-0.33
75,000	Scaled (c)	3.50	3.86	-0.36
1,000	Unscaled	1.41	1.38	0.03

Notes

- (a) For each car, the emissions are integrated from the beginning mileage to the ending mileage and expressed as a rate in g/mi. Each figure is the mean of the car rates, weighting models by 1988 sales.
- (b) These numbers give the average difference in emissions (HiTEC 3000 minus EEE).
- (c) The HiTEC 3000 emissions are rescaled by subtraction of the initial difference between HiTEC 3000 and EEE, given in the final row of the table.
- (d) Each figure is the mean of the car-means at the given mileage.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Mean Effects of HiTEC 3000

Data Set: ETHYL4S3

Pollutant: Hydrocarbons

OBSERVED INTEGRATED EMISSIONS PER MILE

Beginning Mileage	Ending Mileage	Scaling	Mean Integrated Emissions (a)		HiTEC 3000 Effect (b) (g/mi)
			HiTEC 3000 (g/mi)	EEE (g/mi)	
1,000	50,000	Unscaled	0.279	0.264	0.015
1,000	50,000	Scaled (c)	0.281	0.264	0.017
50,000	75,000	Unscaled	0.341	0.347	-0.006
50,000	75,000	Scaled (c)	0.343	0.347	-0.003
1,000	75,000	Unscaled	0.299	0.291	0.008
1,000	75,000	Scaled (c)	0.301	0.291	0.010

OBSERVED MEAN EMISSIONS

Mileage	Scaling	Weighted Average Emissions (d)		HiTEC 3000 Effect (b) (g/mi)
		HiTEC 3000 (g/mi)	EEE (g/mi)	
25,000	Unscaled	0.274	0.272	0.002
25,000	Scaled (c)	0.277	0.272	0.005
50,000	Unscaled	0.341	0.344	-0.003
50,000	Scaled (c)	0.343	0.344	-0.001
75,000	Unscaled	0.340	0.336	0.004
75,000	Scaled (c)	0.343	0.336	0.006
1,000	Unscaled	0.159	0.162	-0.002

Notes

- (a) For each car, the emissions are integrated from the beginning mileage to the ending mileage and expressed as a rate in g/mi. Each figure is the mean of the car rates, weighting models by 1988 sales.
- (b) These numbers give the average difference in emissions (HiTEC 3000 minus EEE).
- (c) The HiTEC 3000 emissions are rescaled by subtraction of the initial difference between HiTEC 3000 and EEE, given in the final row of the table.
- (d) Each figure is the mean of the car-means at the given mileage.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Mean Effects of HiTEC 3000

Data Set: ETHYL4S3

Pollutant: Nitrogen Oxides

OBSERVED INTEGRATED EMISSIONS PER MILE

Beginning Mileage	Ending Mileage	Scaling	Mean Integrated Emissions (a)		HiTEC 3000 Effect (b) (g/mi)
			HiTEC 3000 (g/mi)	EEE (g/mi)	
1,000	50,000	Unscaled	0.44	0.49	-0.05
1,000	50,000	Scaled (c)	0.42	0.49	-0.07
50,000	75,000	Unscaled	0.47	0.67	-0.20
50,000	75,000	Scaled (c)	0.45	0.67	-0.22
1,000	75,000	Unscaled	0.45	0.55	-0.10
1,000	75,000	Scaled (c)	0.43	0.55	-0.12

OBSERVED MEAN EMISSIONS

Mileage	Scaling	Weighted Average Emissions (d)		HiTEC 3000 Effect (b) (g/mi)
		HiTEC 3000 (g/mi)	EEE (g/mi)	
25,000	Unscaled	0.48	0.52	-0.04
25,000	Scaled (c)	0.47	0.52	-0.05
50,000	Unscaled	0.46	0.58	-0.12
50,000	Scaled (c)	0.44	0.58	-0.14
75,000	Unscaled	0.46	0.72	-0.26
75,000	Scaled (c)	0.45	0.72	-0.28
1,000	Unscaled	0.35	0.34	0.02

Notes

- (a) For each car, the emissions are integrated from the beginning mileage to the ending mileage and expressed as a rate in g/mi. Each figure is the mean of the car rates, weighting models by 1988 sales.
- (b) These numbers give the average difference in emissions (HiTEC 3000 minus EEE).
- (c) The HiTEC 3000 emissions are rescaled by subtraction of the initial difference between HiTEC 3000 and EEE, given in the final row of the table.
- (d) Each figure is the mean of the car-means at the given mileage.

Ethyl Corporation HiTEC 3000 Fleet Testing Program: Part

Mean Effects of HiTEC 3000

Data Set: ETHYL4S3

Pollutant: Carbon Monoxide

OBSERVED INTEGRATED EMISSIONS PER MILE

Beginning Mileage	Ending Mileage	Scaling	Mean Integrated Emissions (a)		HiTEC 3000 Effect (b) (g/mi)
			HiTEC 3000 (g/mi)	EEE (g/mi)	
1,000	50,000	Unscaled	2.79	2.85	-0.06
1,000	50,000	Scaled (c)	2.75	2.85	-0.09
50,000	75,000	Unscaled	3.45	4.25	-0.80
50,000	75,000	Scaled (c)	3.42	4.25	-0.83
1,000	75,000	Unscaled	3.01	3.31	-0.31
1,000	75,000	Scaled (c)	2.97	3.31	-0.34

OBSERVED MEAN EMISSIONS

Mileage	Scaling	Weighted Average Emissions (d)		HiTEC 3000 Effect (b) (g/mi)
		HiTEC 3000 (g/mi)	EEE (g/mi)	
25,000	Unscaled	2.83	3.03	-0.20
25,000	Scaled (c)	2.79	3.03	-0.23
50,000	Unscaled	3.54	3.95	-0.41
50,000	Scaled (c)	3.50	3.95	-0.45
75,000	Unscaled	3.20	3.92	-0.72
75,000	Scaled (c)	3.17	3.92	-0.75
1,000	Unscaled	1.41	1.38	0.03

Notes

- (a) For each car, the emissions are integrated from the beginning mileage to the ending mileage and expressed as a rate in g/mi. Each figure is the mean of the car rates, weighting models by 1988 sales.
- (b) These numbers give the average difference in emissions (HiTEC 3000 minus EEE).
- (c) The HiTEC 3000 emissions are rescaled by subtraction of the initial difference between HiTEC 3000 and EEE, given in the final row of the table.
- (d) Each figure is the mean of the car-means at the given mileage.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Mean Effects of HiTEC 3000

Data Set: ETHYL4S4

Pollutant: Hydrocarbons

OBSERVED INTEGRATED EMISSIONS PER MILE

Beginning Mileage	Ending Mileage	Scaling	Mean Integrated Emissions (a)		HiTEC 3000 Effect (b) (g/mi)
			HiTEC 3000 (g/mi)	EEE (g/mi)	
1,000	50,000	Unscaled	0.278	0.262	0.016
1,000	50,000	Scaled (c)	0.280	0.262	0.019
50,000	75,000	Unscaled	0.353	0.335	0.018
50,000	75,000	Scaled (c)	0.355	0.335	0.020
1,000	75,000	Unscaled	0.303	0.286	0.017
1,000	75,000	Scaled (c)	0.305	0.286	0.019

OBSERVED MEAN EMISSIONS

Mileage	Scaling	Weighted Average Emissions (d)		HiTEC 3000 Effect (b) (g/mi)
		HiTEC 3000 (g/mi)	EEE (g/mi)	
25,000	Unscaled	0.274	0.271	0.003
25,000	Scaled (c)	0.277	0.271	0.006
50,000	Unscaled	0.339	0.336	0.003
50,000	Scaled (c)	0.341	0.336	0.005
75,000	Unscaled	0.358	0.329	0.029
75,000	Scaled (c)	0.360	0.329	0.031
1,000	Unscaled	0.159	0.162	-0.002

Notes

- (a) For each car, the emissions are integrated from the beginning mileage to the ending mileage and expressed as a rate in g/mi. Each figure is the mean of the car rates, weighting models by 1988 sales.
- (b) These numbers give the average difference in emissions (HiTEC 3000 minus EEE).
- (c) The HiTEC 3000 emissions are rescaled by subtraction of the initial difference between HiTEC 3000 and EEE, given in the final row of the table.
- (d) Each figure is the mean of the car-means at the given mileage.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Mean Effects of HiTEC 3000

Data Set: ETHYL4S4

Pollutant: Nitrogen Oxides

OBSERVED INTEGRATED EMISSIONS PER MILE

<u>Beginning Mileage</u>	<u>Ending Mileage</u>	<u>Scaling</u>	<u>Mean Integrated Emissions (a)</u>		<u>HiTEC 3000 Effect (b) (g/mi)</u>
			<u>HiTEC 3000 (g/mi)</u>	<u>EEE (g/mi)</u>	
1,000	50,000	Unscaled	0.43	0.49	-0.05
1,000	50,000	Scaled (c)	0.42	0.49	-0.07
50,000	75,000	Unscaled	0.47	0.65	-0.19
50,000	75,000	Scaled (c)	0.45	0.65	-0.20
1,000	75,000	Unscaled	0.44	0.54	-0.10
1,000	75,000	Scaled (c)	0.43	0.54	-0.11

OBSERVED MEAN EMISSIONS

<u>Mileage</u>	<u>Scaling</u>	<u>Weighted Average Emissions (d)</u>		<u>HiTEC 3000 Effect (b) (g/mi)</u>
		<u>HiTEC 3000 (g/mi)</u>	<u>EEE (g/mi)</u>	
25,000	Unscaled	0.48	0.52	-0.03
25,000	Scaled (c)	0.47	0.52	-0.05
50,000	Unscaled	0.43	0.55	-0.12
50,000	Scaled (c)	0.41	0.55	-0.14
75,000	Unscaled	0.47	0.72	-0.25
75,000	Scaled (c)	0.46	0.72	-0.27
1,000	Unscaled	0.35	0.34	0.02

Notes

- (a) For each car, the emissions are integrated from the beginning mileage to the ending mileage and expressed as a rate in g/mi. Each figure is the mean of the car rates, weighting models by 1988 sales.
- (b) These numbers give the average difference in emissions (HiTEC 3000 minus EEE).
- (c) The HiTEC 3000 emissions are rescaled by subtraction of the initial difference between HiTEC 3000 and EEE, given in the final row of the table.
- (d) Each figure is the mean of the car-means at the given mileage.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Mean Effects of HiTEC 3000

Data Set: ETHYL4S4

Pollutant: Carbon Monoxide

OBSERVED INTEGRATED EMISSIONS PER MILE

Beginning Mileage	Ending Mileage	Scaling	Mean Integrated Emissions (a)		HiTEC 3000 Effect (b) (g/mi)
			HiTEC 3000 (g/mi)	EEE (g/mi)	
1,000	50,000	Unscaled	2.76	2.82	-0.06
1,000	50,000	Scaled (c)	2.73	2.82	-0.09
50,000	75,000	Unscaled	3.63	4.04	-0.41
50,000	75,000	Scaled (c)	3.59	4.04	-0.45
1,000	75,000	Unscaled	3.05	3.23	-0.17
1,000	75,000	Scaled (c)	3.02	3.23	-0.21

OBSERVED MEAN EMISSIONS

Mileage	Scaling	Weighted Average Emissions (d)		HiTEC 3000 Effect (b) (g/mi)
		HiTEC 3000 (g/mi)	EEE (g/mi)	
25,000	Unscaled	2.83	3.08	-0.26
25,000	Scaled (c)	2.79	3.08	-0.29
50,000	Unscaled	3.44	3.83	-0.40
50,000	Scaled (c)	3.41	3.83	-0.43
75,000	Unscaled	3.52	3.84	-0.33
75,000	Scaled (c)	3.48	3.84	-0.36
1,000	Unscaled	1.41	1.38	0.03

Notes

- (a) For each car, the emissions are integrated from the beginning mileage to the ending mileage and expressed as a rate in g/mi. Each figure is the mean of the car rates, weighting models by 1988 sales.
- (b) These numbers give the average difference in emissions (HiTEC 3000 minus EEE).
- (c) The HiTEC 3000 emissions are rescaled by subtraction of the initial difference between HiTEC 3000 and EEE, given in the final row of the table.
- (d) Each figure is the mean of the car-means at the given mileage.

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Linear Regression Slopes Test
 50,000 Mile Analysis
 Data Set ETHYL4S2
 Pollutant Hydrocarbons

Model	Deterioration Rate(a) (rate / 10,000 mi) EEE HT3		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
D	0.077	0.091	+	3.18
E	0.021	0.013	-	98.34
F	0.108	0.098	-	94.17
T	0.048	0.048	+	47.05
C	0.010	0.017	+	2.41
G	0.006	0.013	+	0.35
H	0.031	0.033	+	32.25
I	0.002	0.006	+	14.95
Weighted Average(c)	0.035	0.036	+	36.40

EPA Sign Test: Observation of 6 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 14.45 percent significance level(b).

Weighted Average Test: The hypothesis of no overall adverse HiTEC 3000 effect is rejected at the 36.40 percent significance level(b).

Notes:

- The deterioration rate is the rate of increase per 10,000 miles (slope of the linear regression line).
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
 March 21, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Linear Regression Slopes Test
 50,000 Mile Analysis
 Data Set ETHYL4S2
 Pollutant Nitrogen Oxides

Model	Deterioration Rate(a) (rate / 10,000 mi) EEE HT3		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
D	-0.04	-0.03	+	19.40
E	0.04	0.04	+	48.19
F	0.10	0.03	-	100.00
T	-0.01	0.01	+	6.68
C	0.06	0.02	-	100.00
G	0.03	0.03	-	73.41
H	0.02	-0.02	-	99.45
I	0.03	0.02	-	83.36
Weighted Average(c)	0.03	0.01	-	100.00

EPA Sign Test: Observation of 3 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 85.55 percent significance level(b).

Weighted Average Test: The hypothesis of no overall adverse HiTEC 3000 effect is rejected at the 100.00 percent significance level(b).

Notes:

- The deterioration rate is the rate of increase per 10,000 miles (slope of the linear regression line).
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
 March 21, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Linear Regression Slopes Test
 50,000 Mile Analysis
 Data Set ETHYL4S2
 Pollutant Carbon Monoxide

Model	Deterioration Rate(a) (rate / 10,000 mi) EEE HT3		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
D	0.82	0.80	-	62.24
E	0.80	0.58	-	99.69
F	0.35	0.17	-	100.00
T	0.79	0.69	-	94.45
C	0.29	0.33	+	27.70
G	0.20	0.20	-	58.33
H	0.61	0.60	-	57.26
I	0.17	0.13	-	81.47
Weighted Average(c)	0.48	0.42	-	99.91

EPA Sign Test: Observation of 1 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 99.61 percent significance level(b).

Weighted Average Test: The hypothesis of no overall adverse HiTEC 3000 effect is rejected at the 99.91 percent significance level(b).

Notes:

- The deterioration rate is the rate of increase per 10,000 miles (slope of the linear regression line).
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures.

Systems Applications Inc.
 March 21, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Linear Regression Deterioration Factors Test

50,000 Mile Analysis

Data Set ETHYL4S2

Pollutant Hydrocarbons

Model	Deterioration Factor(a)		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
	EEE	HT3		
D	2.167	2.291	+	24.59
E	1.792	1.394	-	99.42
F	3.042	2.687	-	92.38
T	2.049	1.894	-	90.73
C	1.321	1.455	+	12.41
G	1.258	1.486	+	2.50
H	1.715	1.778	+	31.51
I	1.064	1.141	+	16.33
Weighted Average(c)	1.767	1.725	-	78.07

EPA Sign Test: Observation of 5 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 36.33 percent significance level(b).

Weighted Average Test: The hypothesis of no overall adverse HiTEC 3000 effect is rejected at the 78.07 percent significance level(b).

Notes:

- The deterioration factor is the fitted (from the linear regression) 50,000 mile emissions divided by the fitted 4,000 mile emissions.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures. The weighted average deterioration factor is not the ratio of the averages at 4,000 and 50,000 miles.

Systems Applications Inc.
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Ethyl Corporation HiTEC 3000 Fleet Testing Program

Linear Regression Deterioration Factors Test
 50,000 Mile Analysis
 Data Set ETHYL4S2
 Pollutant Nitrogen Oxides

Model	Deterioration Factor(a)		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
	EEE	HT3		
D	0.64	0.74	+	10.45
E	1.79	1.83	+	39.62
F	1.71	1.23	-	99.99
T	0.92	1.05	+	8.90
C	2.32	1.46	-	99.71
G	1.55	1.45	-	71.30
H	1.23	0.83	-	99.20
I	1.34	1.23	-	77.94
Weighted Average(c)	1.45	1.20	-	100.00

EPA Sign Test: Observation of 3 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 85.55 percent significance level(b).

Weighted Average Test: The hypothesis of no overall adverse HiTEC 3000 effect is rejected at the 100.00 percent significance level(b).

Notes:

- The deterioration factor is the fitted (from the linear regression) 50,000 mile emissions divided by the fitted 4,000 mile emissions.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures. The weighted average deterioration factor is not the ratio of the averages at 4,000 and 50,000 miles.

Systems Applications Inc.
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Ethyl Corporation HiTEC 3000 Fleet Testing Program

Linear Regression Deterioration Factors Test
 50,000 Mile Analysis
 Data Set ETHYL4S2
 Pollutant Carbon Monoxide

Model	Deterioration Factor(a)		Sign ('+' = adverse HT3 effect)	T-test Significance Level (%) (b)
	EEE	HT3		
D	3.16	3.03	-	67.80
E	2.42	1.77	-	99.94
F	2.98	2.09	-	99.96
T	2.87	2.38	-	97.23
C	1.76	1.80	+	41.94
G	1.71	1.67	-	57.63
H	2.48	2.69	+	21.96
I	1.40	1.30	-	79.72
Weighted Average(c)	2.29	2.07	-	99.16

EPA Sign Test: Observation of 2 '+' sign(s) in 8 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 96.48 percent significance level(b).

Weighted Average Test: The hypothesis of no overall adverse HiTEC 3000 effect is rejected at the 99.16 percent significance level(b).

Notes:

- The deterioration factor is the fitted (from the linear regression) 50,000 mile emissions divided by the fitted 4,000 mile emissions.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.
- The weights for the weighted averages are proportional to 1988 sales figures. The weighted average deterioration factor is not the ratio of the averages at 4,000 and 50,000 miles.

Systems Applications Inc.
 March 21, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Violation Mileage Test
 50,000 Mile Analysis
 (based on linear regression)
 Data Set ETHYL4S2
 Pollutant Hydrocarbons

Model	Violation Mileage(a) (miles)		Sign ('+' = adverse HT3 effect)
	EEE	HT3	
D	17,522	13,176	+
E	99,000	99,000	0
F	19,275	18,753	+
T	46,361	38,240	+
C	99,000	99,000	0
G	99,000	99,000	0
H	99,000	99,000	0
I	99,000	99,000	0

EPA Sign Test: Observation of 3 '+' sign(s) in 3 trial(s) rejects the hypothesis of no adverse HiTEC 3000 effect at the 12.50 percent significance level(b).
 (For the purpose of the sign test, only observations with sign = + or - are counted as trials.)

Notes:

- The violation mileage is the mileage (fitted by the linear regression line) at which the standard is reached. Violation mileage = 0 if the zero mile emissions exceed the standard. Violation mileage = 99,000 if the regression line lies entirely below the standard between 0 and 50,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.

Systems Applications Inc.
 March 21, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Violation Mileage Test
 50,000 Mile Analysis
 (based on linear regression)
 Data Set ETHYL4S2
 Pollutant Nitrogen Oxides

Model	Violation Mileage(a) (miles)		Sign ('+' = adverse HT3 effect)
	EEE	HT3	
D	99,000	99,000	0
E	99,000	99,000	0
F	42,297	99,000	-
T	99,000	99,000	0
C	99,000	99,000	0
G	99,000	99,000	0
H	99,000	99,000	0
I	99,000	99,000	0

EPA Sign Test: Observation of 0 '+' sign(s) in 1 trial(s) rejects the hypothesis of no adverse HiTEC 3000 effect at the 100.00 percent significance level(b). (For the purpose of the sign test, only observations with sign = + or - are counted as trials.)

Notes:

- The violation mileage is the mileage (fitted by the linear regression line) at which the standard is reached. Violation mileage = 0 if the zero mile emissions exceed the standard. Violation mileage = 99,000 if the regression line lies entirely below the standard between 0 and 50,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.

Systems Applications Inc.
 March 21, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Violation Mileage Test
 50,000 Mile Analysis
 (based on linear regression)
 Data Set ETHYL4S2
 Pollutant Carbon Monoxide

Model	Violation Mileage(a) (miles)		Sign ('+' = adverse HT3 effect)
	EEE	HT3	
D	24,426	23,875	+
E	13,911	2,397	+
F	99,000	99,000	0
T	22,236	19,725	+
C	99,000	49,381	+
G	99,000	99,000	0
H	28,463	33,236	-
I	99,000	99,000	0

EPA Sign Test: Observation of 4 '+' sign(s) in 5 trial(s) rejects the hypothesis of no adverse HiTEC 3000 effect at the 18.75 percent significance level(b).
 (For the purpose of the sign test, only observations with sign = + or - are counted as trials.)

Notes:

- The violation mileage is the mileage (fitted by the linear regression line) at which the standard is reached. Violation mileage = 0 if the zero mile emissions exceed the standard. Violation mileage = 99,000 if the regression line lies entirely below the standard between 0 and 50,000 miles.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.

Systems Applications Inc.
 March 21, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Maximum Percentage of Vehicles Failing Standard Test

50,000 Mile Analysis
(based on linear regression)

Data Set ETHYL4S2

Pollutant Hydrocarbons

Model	Maximum Estimated Percentage Failures (mileage)(a)		Sign ('+' = adverse HT3 effect)
	EEE	HT3	
D	100.00 (50,000)	100.00 (50,000)	0
E	0.00 (50,000)	0.00 (50,000)	0
F	100.00 (50,000)	100.00 (50,000)	0
T	69.50 (50,000)	95.13 (50,000)	+
C	0.00 (50,000)	0.00 (50,000)	0
G	0.00 (50,000)	0.00 (50,000)	0
H	4.23 (50,000)	5.19 (50,000)	+
I	0.00 (50,000)	0.00 (50,000)	0

EPA Sign Test: Observation of 2 '+' sign(s) in 2 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 25.00 percent significance level(b).
(For the purpose of the sign test, only observations with sign = + or - are counted as trials.)

Notes:

- For each mileage the percentage of vehicles failing the standard is estimated using the linear regression line. The first figure is the maximum percentage over all mileages from 0 to 50,000 miles. The figure in parentheses is the mileage at which the maximum occurs and is 0 if the slope is negative and 50,000 if the slope is positive.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.

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Ethyl Corporation HiTEC 3000 Fleet Testing Program

Maximum Percentage of Vehicles Failing Standard Test
 50,000 Mile Analysis
 (based on linear regression)
 Data Set ETHYL4S2
 Pollutant Nitrogen Oxides

Model	Maximum Estimated Percentage Failures (mileage)(a)		Sign ('+' = adverse HT3 effect)
	EEE	HT3	
D	0.00 (0)	0.00 (0)	0
E	0.00 (50,000)	0.00 (50,000)	0
F	73.82 (50,000)	0.95 (50,000)	-
T	3.49 (0)	0.01 (50,000)	-
C	0.00 (50,000)	0.00 (50,000)	0
G	0.00 (50,000)	0.00 (50,000)	0
H	0.00 (50,000)	0.00 (0)	0
I	0.00 (50,000)	0.00 (50,000)	0

EPA Sign Test: Observation of 0 '+' sign(s) in 2 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 100.00 percent significance level(b). (For the purpose of the sign test, only observations with sign = + or - are counted as trials.)

Notes:

- For each mileage the percentage of vehicles failing the standard is estimated using the linear regression line. The first figure is the maximum percentage over all mileages from 0 to 50,000 miles. The figure in parentheses is the mileage at which the maximum occurs and is 0 if the slope is negative and 50,000 if the slope is positive.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.

Systems Applications Inc.
 March 22, 1990

Ethyl Corporation HiTEC 3000 Fleet Testing Program

Maximum Percentage of Vehicles Failing Standard Test
 50,000 Mile Analysis
 (based on linear regression)
 Data Set ETHYL4S2
 Pollutant Carbon Monoxide

Model	Maximum Estimated Percentage Failures (mileage)(a)		Sign ('+' = adverse HT3 effect)
	EEE	HT3	
D	100.00 (50,000)	100.00 (50,000)	0
E	100.00 (50,000)	100.00 (50,000)	0
F	0.00 (50,000)	0.00 (50,000)	0
T	100.00 (50,000)	99.99 (50,000)	-
C	31.69 (50,000)	51.38 (50,000)	+
G	0.09 (50,000)	0.07 (50,000)	-
H	99.58 (50,000)	97.80 (50,000)	-
I	4.02 (50,000)	1.84 (50,000)	-

EPA Sign Test: Observation of 1 '+' sign(s) in 5 trials rejects the hypothesis of no adverse HiTEC 3000 effect at the 96.87 percent significance level(b).
 (For the purpose of the sign test, only observations with sign = + or - are counted as trials.)

Notes:

- For each mileage the percentage of vehicles failing the standard is estimated using the linear regression line. The first figure is the maximum percentage over all mileages from 0 to 50,000 miles. The figure in parentheses is the mileage at which the maximum occurs and is 0 if the slope is negative and 50,000 if the slope is positive.
- The lower the significance level, the greater the evidence of an adverse HiTEC 3000 effect.

Systems Applications Inc.
 March 22, 1990